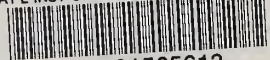


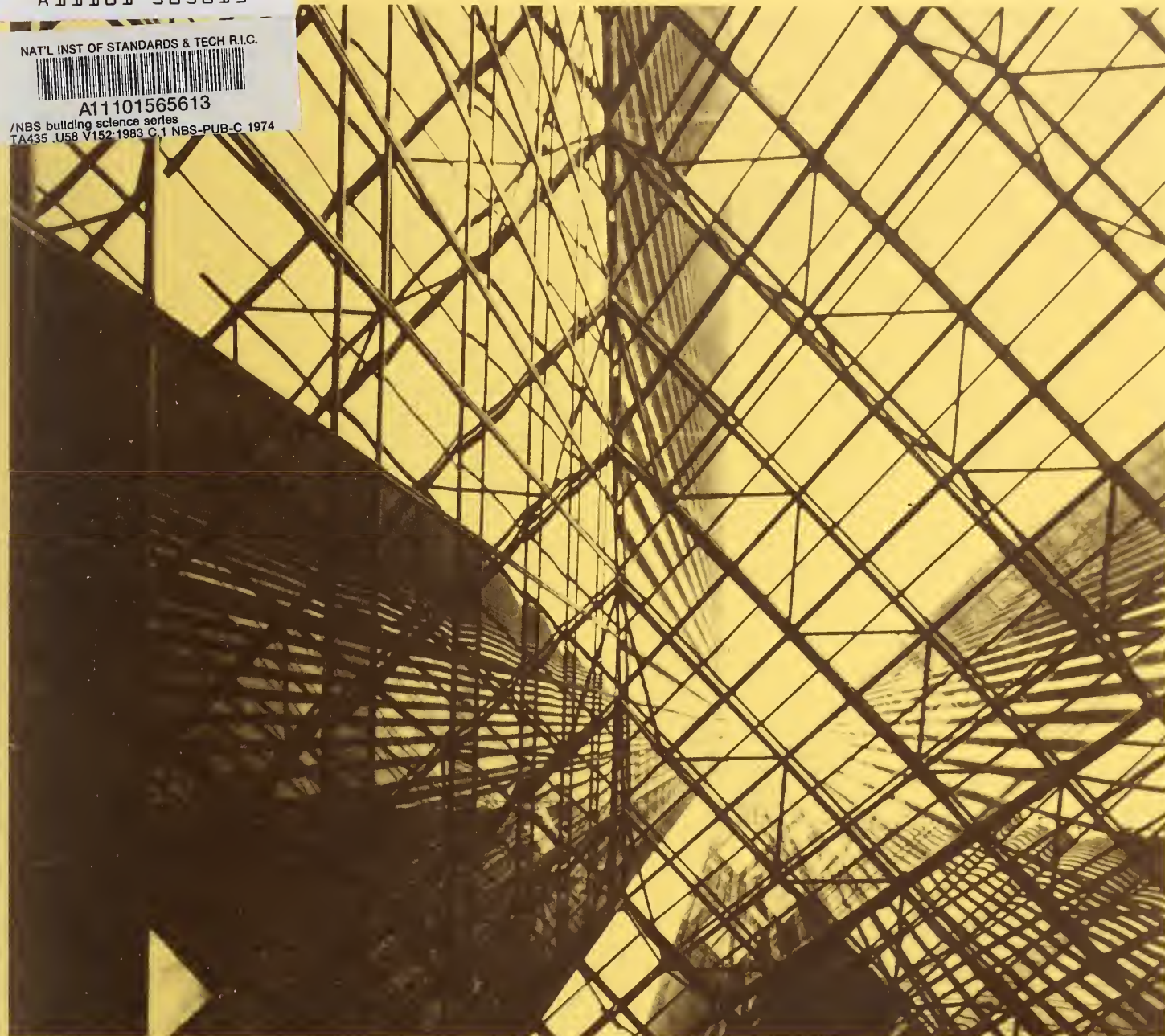
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A Daylighting Model for Building Energy Simulation

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A Daylighting Model for Building Energy Simulation

Gary Gillette

Research Associate
National Fenestration Council
in collaboration with
Thermal Analysis Group
Building Physics Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

Sponsored by:
The National Fenestration Council
3310 Harrison Street
Topeka, KS 66611

and

The U.S. Department of Energy
Buildings Division
1000 Independence Ave., S.W.
Washington, DC 20585



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ABSTRACT

A computer model is outlined for estimating the annual energy performance of a daylighted building. The daylighting model is a system of FORTRAN subroutines designed for inclusion into larger building energy simulation programs such as DOE-2, BLAST, and NBSLD. Once incorporated into the main energy program, these subroutines will allow the existing program to account for the energy tradeoffs associated with natural illumination.

The daylighting model, DALITE, comprises three separate routines to do three separate functions. The first routine generates hourly sky luminances and sky illuminances as well as direct sun illuminance, taking solar radiation and sun position data as input. The second predicts interior daylight illumination at various points within a room due to any number of windows, skylights or clerestories. The last routine adjusts the electric lighting load (via photo-electric controls) in response to the available daylight. Unlike most other daylighting estimation techniques, this model is a dynamic model designed to study how conditions change with time. It has a further advantage in that it can be easily installed into most existing energy models written in FORTRAN 77.

Key Words: building computer simulation, building energy performance, clerestory performance, daylighting, lighting, skylight performance, window performance.

*Cover: Daylight admitted through sloped glazing
in a high-rise office complex.*

PREFACE

This report is one of a series documenting NBS research and analysis efforts in developing energy and cost data to support the Department of Energy/National Bureau of Standards Measurements Program. The work reported in this document was performed under the Research Associate Program between the National Fenestration Council and the National Bureau of Standards. The Research Associate Program was partially supported by the U.S. Department of Energy under the Building Thermal Envelope Systems and Insulating Materials Program (contract no. ORNL/PO-22201).

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Conversion Factors from English to Metric (SI) Units

Physical Quantity	To Convert From Customary Units	To SI Units	Multiply By
Length	ft	m	0.3048
Area	ft ²	m ²	0.0929
Energy	Btu	J	1055
Power	Btu/hr	W	0.2931
Illuminance	fc	lx	10.76
Irradiance	Btu/hr·ft ²	W/m ²	3.155
Luminance	fL	nit (cd/m ²)	3.426

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*Facing page: Daylighting from continuous
skylights in an office mall*



1. INTRODUCTION

With the renewed interest in energy conservation in general, and with daylighting in particular, many in the building profession have become interested in how daylighting impacts the energy performance of a building over time. This interest extends beyond simple daylighting design calculations by including the impact of daylighting strategies on the building lighting, heating, and cooling requirements. The goal has become annual energy consumption not illumination at one point in time. Only since the recent introduction of computers into the building industry, has it been possible to perform an annual energy analyses with any substantial degree of certainty. Today many computer programs exist for estimating energy use in buildings. Among the

best known public domain programs are DOE-2 [1], BLAST [2], and NBSLD [3]; not to mention the host of proprietary programs currently in use [4]. These programs consider most of the major transient energy parameters in buildings. Some are more rigorous than others, and each has its strengths and weaknesses, but few have an integrated daylighting model sufficient for existing daylighting practice.

While there are also computer programs developed exclusively for daylighting analysis, these are designed for rigorous yet static design conditions and are normally too time consuming to be used repetitively for energy studies. In this category are such lighting programs as LUMEN II [5], SUPERLIGHT [6], and CEL-1 [7], which are useful programs for those interested in a careful evaluation of an illuminated space, but are much too rigorous for execution each daylight hour of the year. They also share in a common weakness as far as building energy simulation programs are concerned in that they study only standard sky conditions and are not designed to be responsive to changing weather conditions.

In the following pages, a daylighting model is offered which is specifically designed for use in large-scale building simulation programs. It has been prepared as a set of subroutines that can be incorporated into existing programs with a minimum of effort. The subroutines are short, concise, and computationally fast (normally causing under ten percent of the total CPU time for a full daylighting analysis). They should be compatible with most computer programs currently written in FORTRAN 77, and with only slight modifications could also be revised into FORTRAN IV. In fact, the daylighting algorithms are small enough to put into a micro-computer provided it has a FORTRAN compiler.

*Facing page: The sky hemisphere under partly
cloudy conditions*



2. THE DALITE SUBPROGRAM

2.1 CAPABILITIES

The DALITE subprogram is unique in that it comes as a package, a group of small subroutines, which can be incorporated into most existing building simulation programs. Unlike most other daylighting models, its small packaged form enables it to be fully integrated into a larger building simulation program without requiring excessive computation time. In this way, hourly daylighting analyses can be done simultaneously with the thermal calculations, allowing an assessment of the overall energy impact of daylighting.

The DALITE package is streamlined to be computationally fast and computes only those elements that contribute significantly to the energy performance of the building. While being a simplified model, it is still flexible in its ability to simulate a range of fenestration scenerios - windows, skylights, clerestories, roof monitors, overhangs, sidefins, and almost any combination of these. The subprogram is also fairly even-handed in that it does not concentrate computation time on a few noncritical calculations at the expense of others. For instance, the interreflection model is flexible for use with both sidelighting and toplighting, yet avoids rigorous interflux calculations.

The sky subroutine deals with a continuous range of sky conditions, not just clear or overcast, and needs only the instantaneous solar radiation and sun position as input. From this internally generated availability data, another subroutine estimates the reflected light from surrounding buildings, light from the sky dome, reflected ground light, and internally reflected light. The direct beam illuminance, as a rhomboidal patch of sunlight on the workplane, is also simulated for each aperture that has sunlight falling on it. Thus, the package is capable of performing all critical daylighting/energy calculations, and utilizes information in the existing building simulation program to perform the daylighting analysis.

2.2 INCORPORATING THE SUBPROGRAM INTO AN ENERGY PROGRAM

Although the DALITE subprogram is a complete package and can be prepared as a stand-alone program, its intended purpose is for use as a subroutine package in other energy simulation programs. DALITE and its three subordinate subroutines should be executed as a part of the hourly building load calculations as shown in figure 2.1. From the programmer's point of view, incorporation requires only input/output preparation through a single two-dimensional array (see Appendix B). The instantaneous electric light load and heat-of-lights given as output can be fed into the hourly load compilaton along with the other thermal loads, which are totalled for each zone and sent on to the system and plant compilations to give the total annual energy (see Appendix C).

2.2.1 Subprogram Structure

The DALITE subprogram comprises a sky model (SKYLUM), an interior daylight model (RMLITE), and a lighting load model (LLOAD), each as a separate subroutine. Figure 2.2 illustrates the subroutine structure. DALITE is the master routine coordinating the data from the subroutines and prepares the input/output information. It acts as an interface between the individual components and the main energy program. DALITE is executed only once each daytime hour for any given room but the SKYLUM and RMLITE subroutines are executed, respectively, for each fenestration aperture and for each sensor position. LLOAD is executed once for each sensor each hour. To streamline the program further, the repetitive calculations in the RMLITE model are suppressed once the geometry coefficients have been computed and these coefficients are used each repeated hour, greatly increasing the speed of the program.

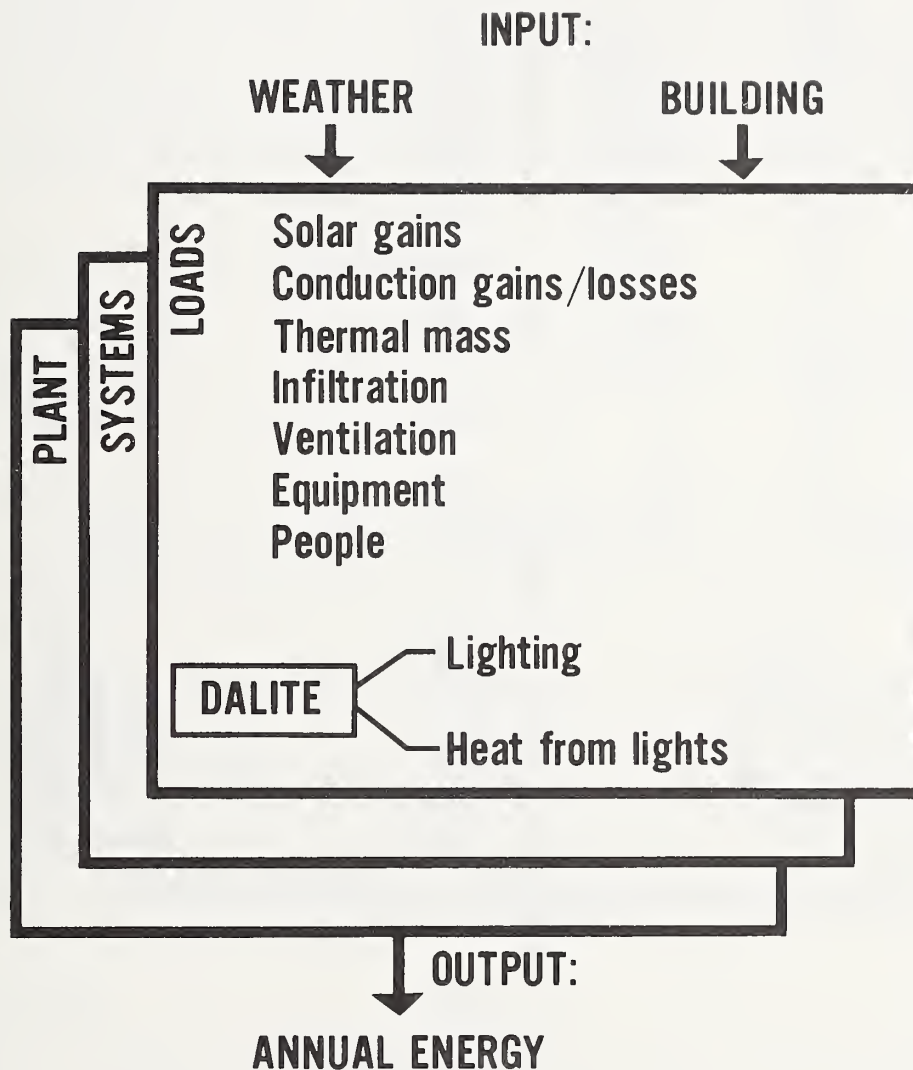


Figure 2.1 The DALITE program as a part of the total energy analysis process

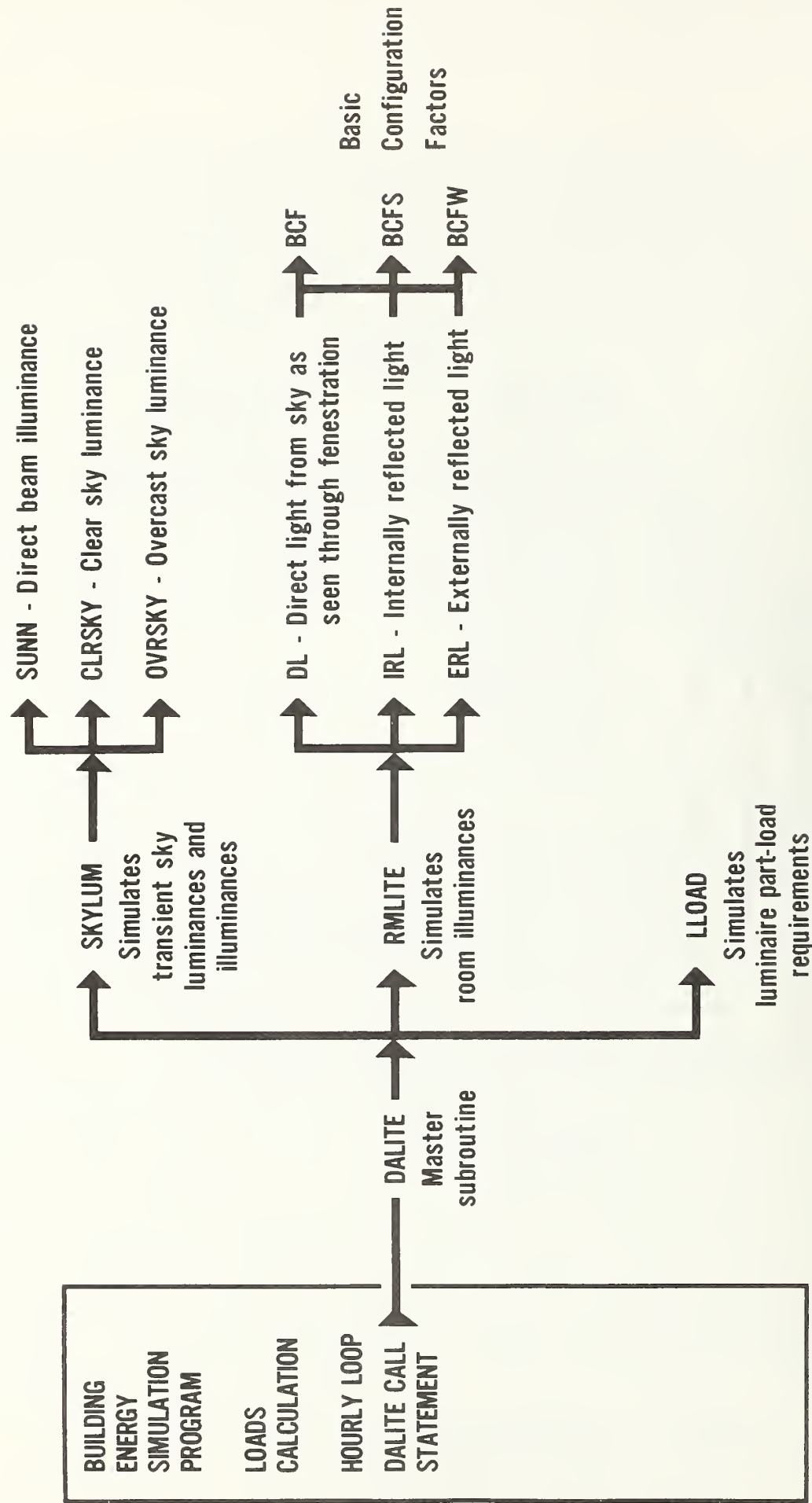


Figure 2.2 DALITE subroutine structure

2.2.2 Input/Output

Input is requested by the main energy program internally at two points during execution of the program: 1) during initialization when the main program is defining building information that remains constant throughout the analysis, and 2) during each repetitive execution when the sky and other conditions change (see Appendix C). A single array is used for storing input and output (I/O) information. The array is sized through parameter statements in the main program to accommodate an arbitrary number of fenestration apertures and dimmer/switch controls. In this way, for a larger (or smaller) capacity of either, adjustments can be made in the array size and the limits on the do-loops. Details of array element assignments are delineated in Appendix C.

2.2.3 Reference and Coordinate Systems

The DALITE routine has its own reference and coordinate systems which positions the building and the sun on the building site, positions the photo sensors in the room, and positions the fenestration on the walls or ceiling. Each reference system is briefly discussed below.

The coordinates of the building's orientation are shown in figure 2.3. Buildings oriented off the north/south axis (as shown) have an azimuth angle correction AZM, where AZM is in degrees clockwise from north. The sun angles SUNAZ and SUNALT are also input in degrees, and are the solar azimuth clockwise from north and solar altitude above the horizon, respectively.

Figures 2.4 and 2.5 illustrate the coordinates used to locate sensor positions and the fenestration. The coordinates of the room and the coordinates of each wall are always referenced to the lower left-hand corner of the plane. For example, to locate a window on a wall, the lower left-hand corner of the window is referenced to the lower left-hand corner of the wall as viewed externally. Skylights and clerestories are located on the ceiling in a similar way. It is important to note that coordinates of each surface, including the floor, are specified in either the height, width or length directions as represented in figure 2.6.

2.3 LIMITATIONS

As is characteristic of any prediction procedure, the daylighting model has limitations. Although the ceiling plane is allowed to be sloped, the room plan is otherwise assumed to be rectangular, meaning that the program cannot simulate interreflections in L-shaped or other non-rectangular geometries. A warning might be made here that when simulating room geometries with depth-to-height ratios greater than two or three to one, interreflected light should not be computed, since the validity of the assumptions used to determine interreflected light is questionable at such room depths. There are also unique types of fenestration designs that cannot be sufficiently represented such as light shelves and domes. However, with wisdom in making the right assumptions these too can be done by approximation and should not be considered a severe weakness; most thermal models do not accurately account for such configurations either. When novel or complex fenestration designs are to be analyzed, a

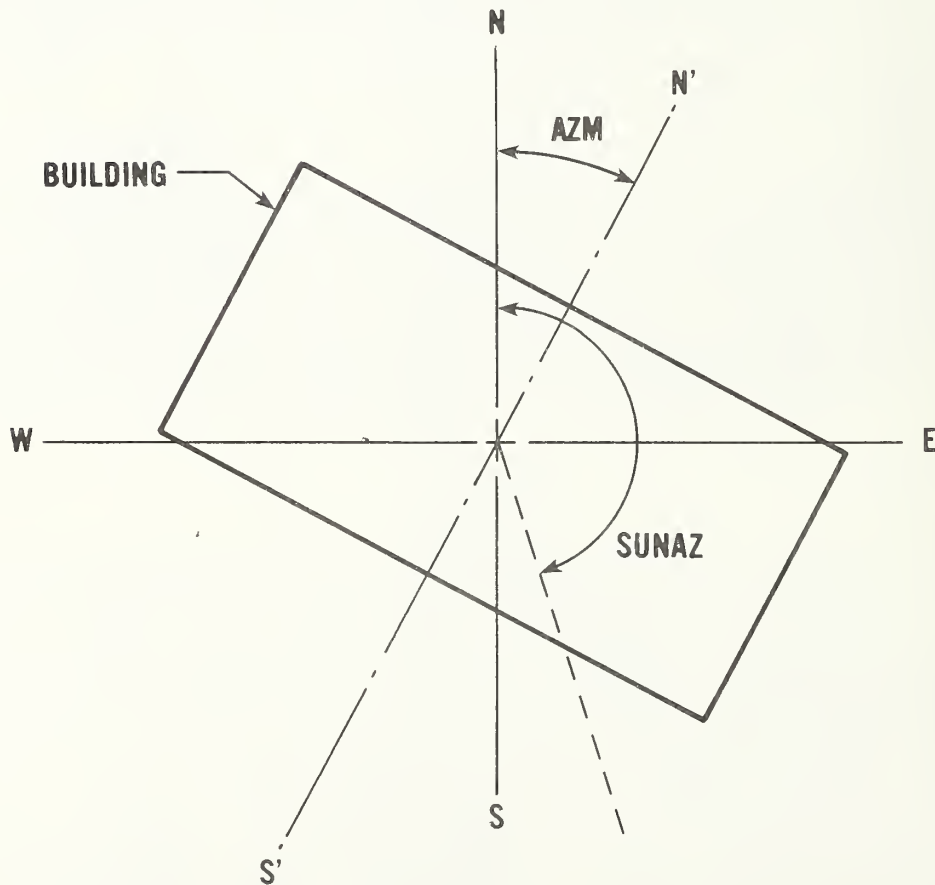
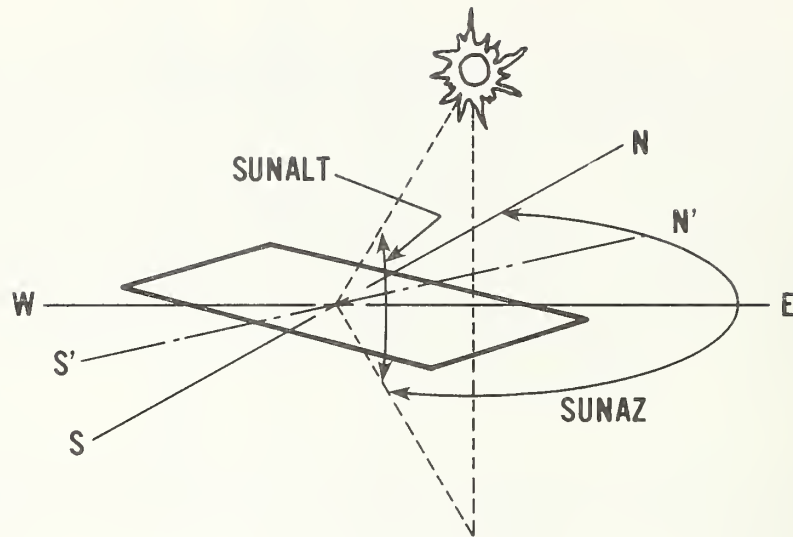


Figure 2.3 Building orientation coordinates

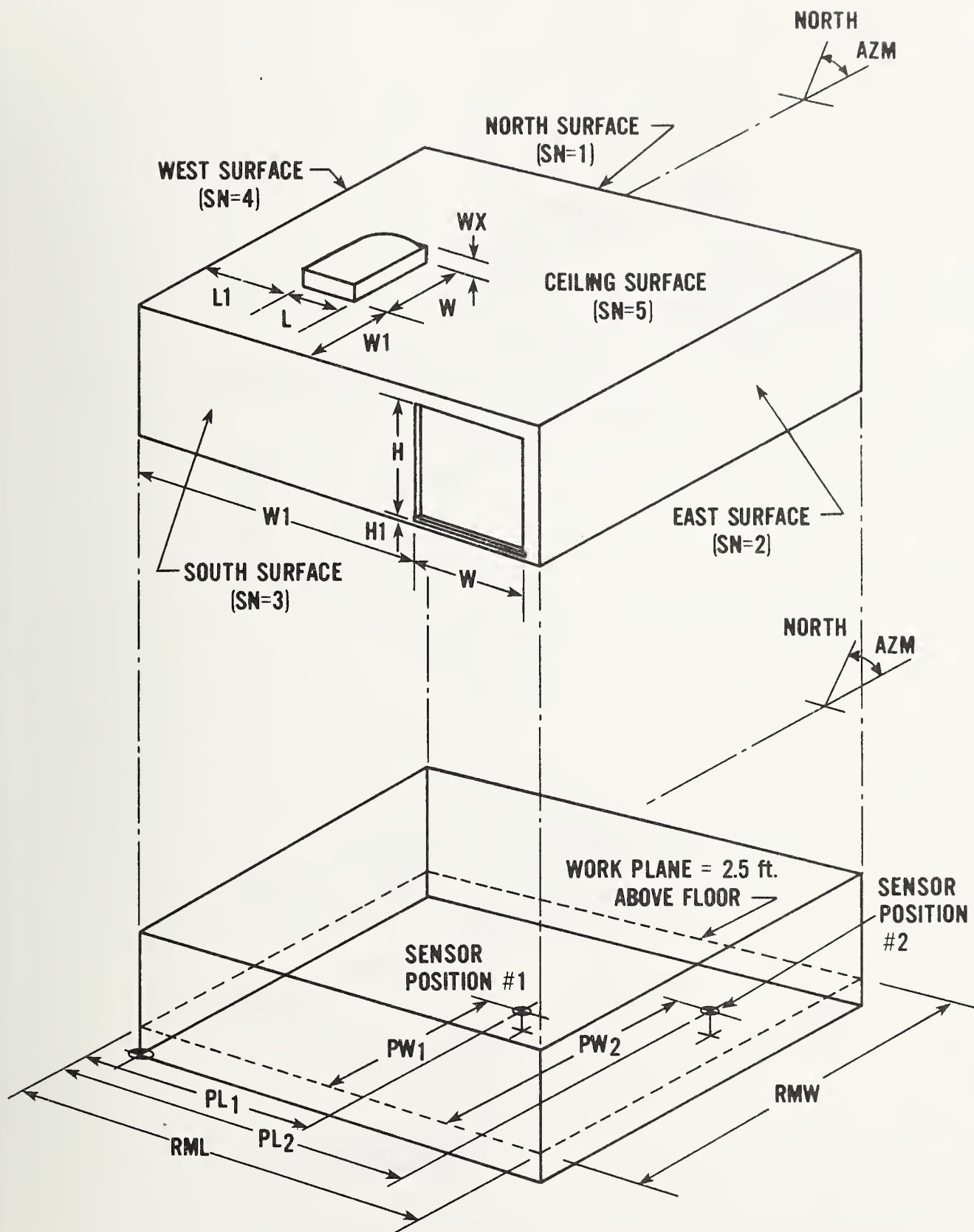


Figure 2.4 Room and fenestration coordinates

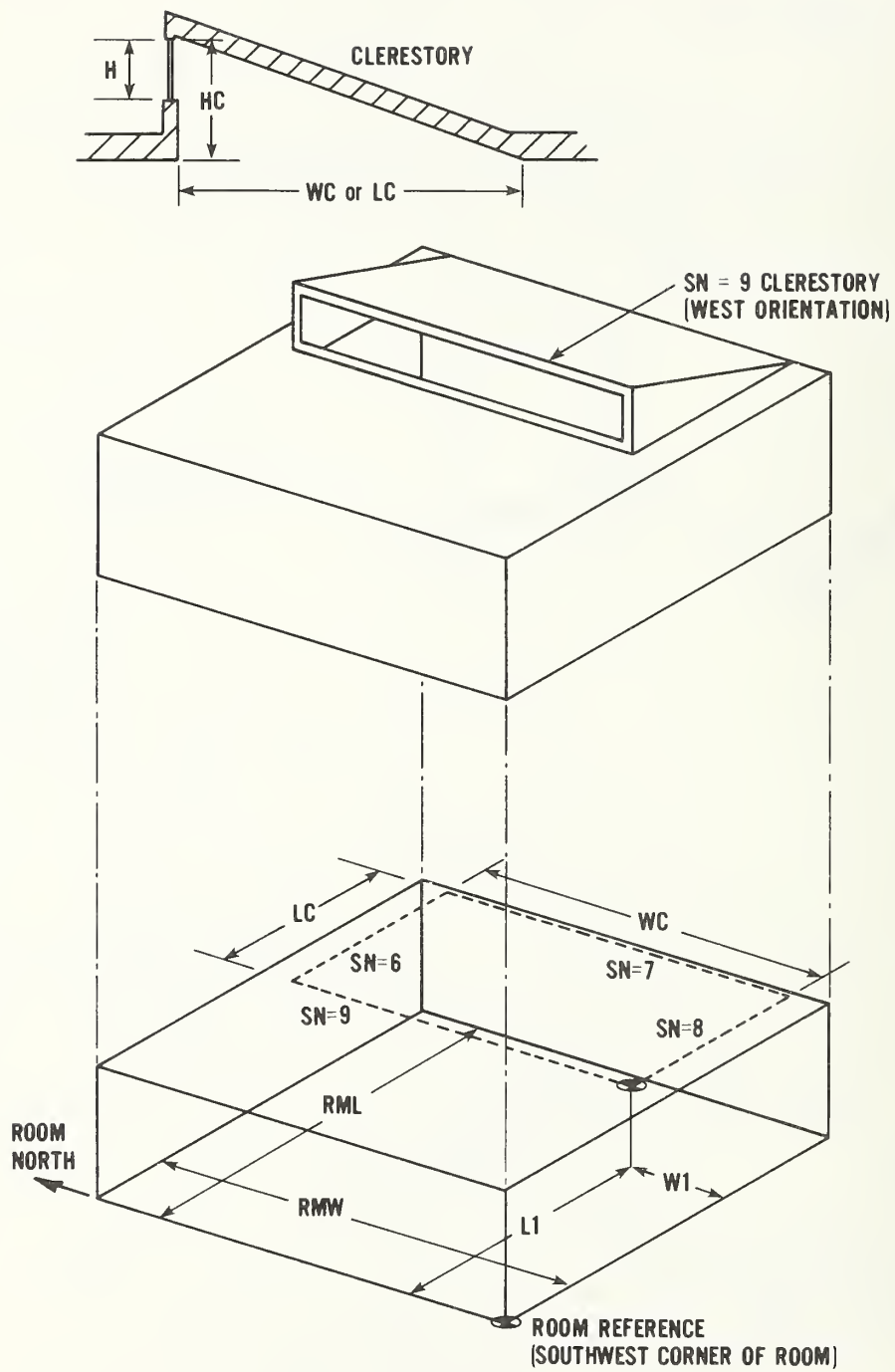
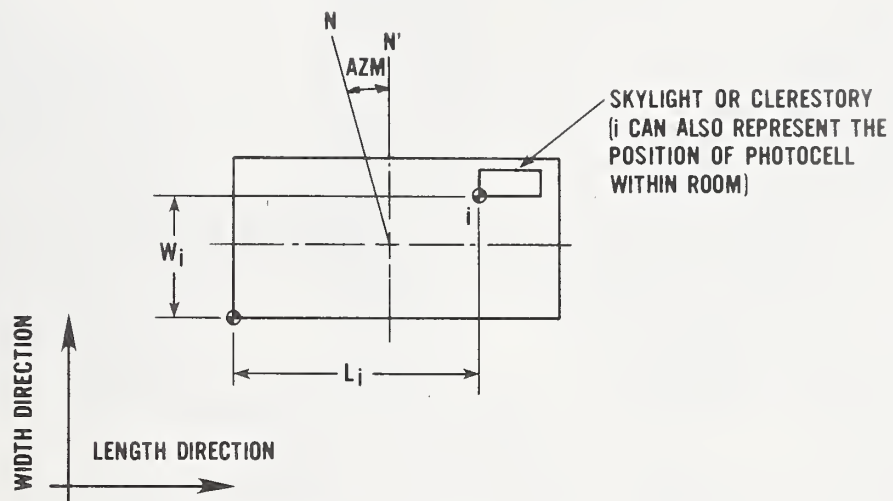
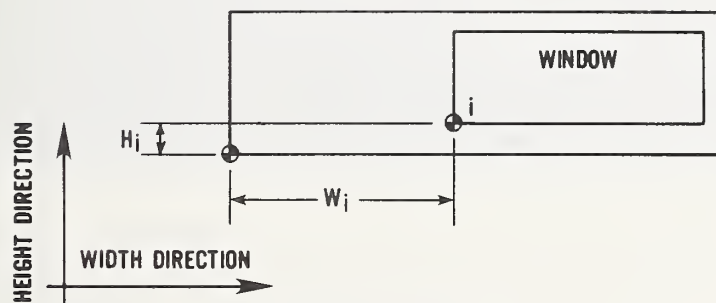


Figure 2.5 Fenestration coordinates for a clerestory



a) FOR CEILINGS AND FLOORS



b) FOR WALL SURFACES

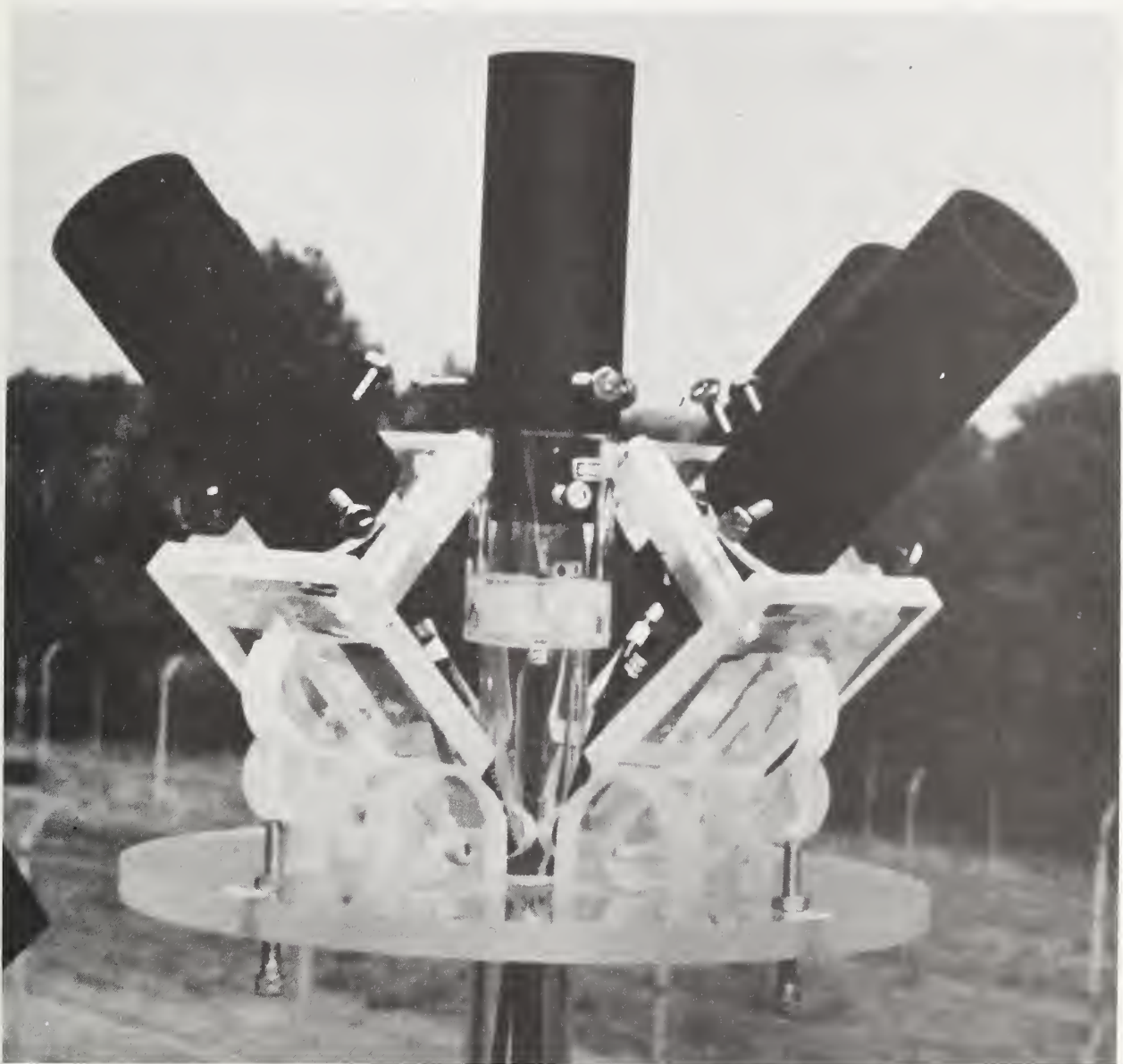
Figure 2.6 Surface coordinates

possible option is to determine the geometric daylight coefficients (see section 2.2.1) apart from the DALITE program using either physical models or manual calculations, and assuming these as constants, simulate the sky and building load interfacing using the remaining daylighting algorithms. Great flexibility can be achieved in this way, with the limits being only the extent at which such coefficients can be obtained.

Glare is not modeled explicitly, but this is intentional. DALITE seeks to simulate the photoelectric control response to changing daylighting conditions, not the user response to those conditions. While it is true that a relationship probably exists between the two, a valid correlation can only be assumed if building occupants respond to a glare problem by applying or adjusting a glare or sun control device, which in turn adjusts the effective transmittance of the fenestration. Since such adjustments are normally modeled as a part of the existing loads program, it is necessary only to replace the specified transmittance with an hourly adjusted value before the call statement to the DALITE subroutine is given.

Another possible limitation may be found in the model's assumption that the rooms are empty. Internal obstructions such as furniture and occupants are not considered as contributors in the lighting calculations even though they do contribute to the thermal latent and sensible loads. Since the daylighting model was developed as a streamlined program, such capabilities were not considered essential.

*Facing page: Measuring the sky luminance
at selected positions in
the sky.*



3. THE SKYLUM ROUTINE

3.1 CAPABILITIES

Since the weather data normally used in building energy programs do not include hourly exterior daylight, such values are generated internally from the available values of solar radiation and sun position. Total and diffuse solar radiation incident upon a horizontal surface, values that are normally computed within the larger existing programs, are used to determine the sky conditions. From this hourly information the sky luminances as seen through each window or skylight are calculated. The intensity of the direct sun and the total illuminance on a horizontal plane is also determined.

Obtaining hourly solar data in any form is a complex issue. For the relatively few locations in North America where hourly values of total horizontal and direct normal solar radiation are recorded, such data can be easily accessed. But for cities where only TRY (Test Reference Year) data are available, the hourly solar radiation must be generated internally using a calculation procedure such as developed by Liu and Jordan [8], Stevenson and Kimura [9], or others [10]. When the more common TRY weather tapes are used, the only hourly sky information provided is a visual (subjective) assessment of the cloud conditions, specified in terms of a cloud cover value and the type of cloud in four different layers. Even when TMY (Typical Meteorological Year) weather tapes or other solar data are used the data itself is normally incomplete and is interpolated for a complete hourly file. Therefore, due to the nature of the input data alone, the sky model carries a degree of uncertainty. The SKYLUM routine assumes that the following solar data are accessible by the time the DALITE subroutine is called: 1) sun altitudes and azimuth, 2) total horizontal solar radiation, and 3) the ratio of diffuse to total horizontal solar radiation. The instantaneous solar altitude and azimuth are used to determine the zenith clear sky luminance; the horizontal solar radiation is used to derive the horizontal illuminance and the overcast sky luminance; the ratio of the diffuse to total radiation (denoted as the cloud ratio, CR hereafter) is used to determine intermediate partly cloudy sky condition. This latter term is discussed in more detail below.

3.2 THE PHASING TECHNIQUE

To capture the variable nature of the sky as it changes with time, a continuous phasing technique is employed. Since skies are often neither perfectly clear nor perfectly overcast, a weighted averaging is done hourly between the two extremes based on the cloud ratio CR described above. The process requires an initial determination of the sky luminance as seen through the fenestration under the clear and overcast conditions, and a phasing technique is done between the two conditions to get the intermediate value actually used as shown in figure 3.1. The intermediate sky luminance at point P thus becomes,

$$L_p = \xi_{clr}(L_{p_{clr}}) + \xi_{ovr}(L_{p_{ovr}})$$

or

$$L_p = \xi_{clr}(L_{p_{clr}}) + (1-\xi_{clr})(L_{p_{ovr}}) \quad (3.1)$$

where,

ξ_{clr} = the clear sky fraction

ξ_{ovr} = the overcast sky fraction

$L_{p_{clr}}$ = the clear sky luminance

$L_{p_{ovr}}$ = the overcast sky luminance.

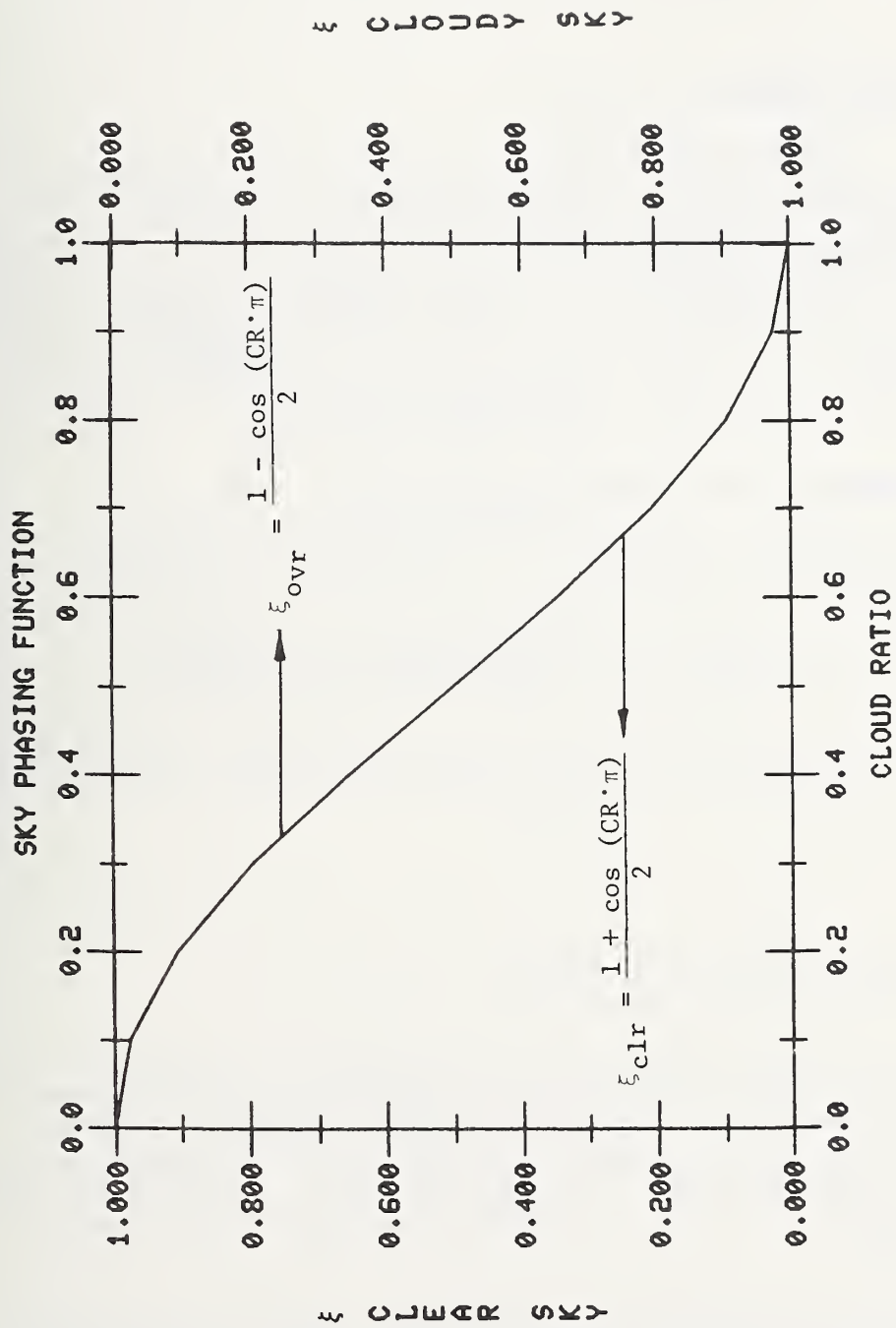


Figure 3.1 Curve used to obtain intermediate sky luminance as a function of cloud ratio

Due to the nature of the CR, a sinusoidal curve was used to interface between sky luminance values. This curve gives expressions for ξ_{clr} and ξ_{ovr} as,

$$\xi_{clr} = \frac{1 + \cos (CR*\pi)}{2} \quad (3.2)$$

and

$$\xi_{ovr} = \frac{1 - \cos (CR*\pi)}{2} \quad (3.3)$$

which provides the slightly biased weighted average in favor of either of the clear or overcast sky condition. It should be pointed out, however, that equations 3.2 and 3.3 do not generate the percentage of the sky in clouds, but rather estimate a weighted average luminance; the cosine curve is this weighting function. From sky measurements it has been noted that cloud ratios of about 0.20 and below are effectively clear skies with possibly only a slight haze present. Likewise, it appears that the blue sky is no longer present after the cloud ratio exceeds about 0.80. The cosine function is simply an attempt at capturing this natural bias toward the extremes.

3.3 THE ZENITH LUMINANCE AND LUMINANCE DISTRIBUTION

For the clear sky luminance at point P in the sky, Kittler's luminance distribution equation [11] is used,

$$L_p \text{ clr} = L_Z \text{ clr} \frac{(1 - e^{-0.32/\sin\theta}) (0.91 + 10e^{-3\psi} + 0.45\cos^2\psi)}{0.274 (0.91 + 10e^{-3(\pi/2-h)} + 0.45 \sin^2 h)} \quad (3.4)$$

where the radian angles θ , ψ , and h are given in figure 3.2. The zenith sky luminance $L_Z \text{ clr}$ for perfectly clear sky conditions is given by the equation

$$L_Z \text{ clr} = a_0 + a_1 h^2 \quad (\text{k cd/m}^2) \quad (3.5)$$

where,

h = the solar altitude in degrees
 a_0, a_1 = atmospheric coefficients as found in table 1.

The coefficients a_0 and a_1 are from Dogniaux [12] with the coefficients for the h^3 term excluded since their contribution is insignificant for this type of application. The values for the Ångström turbidity coefficient β and the precipitable water ω , while not normally available, can be approximated using the classification shown in table 1 (also from Dogniaux). Reference is made to Linke [13] and Nagel [14] for the relationship between β and ω and other atmospheric factors.

Figure 3.3 shows a plot of the NBS sky measurements [15] of clear sky zenith luminance along with curves for the upper and lower limits of equation 3.5.

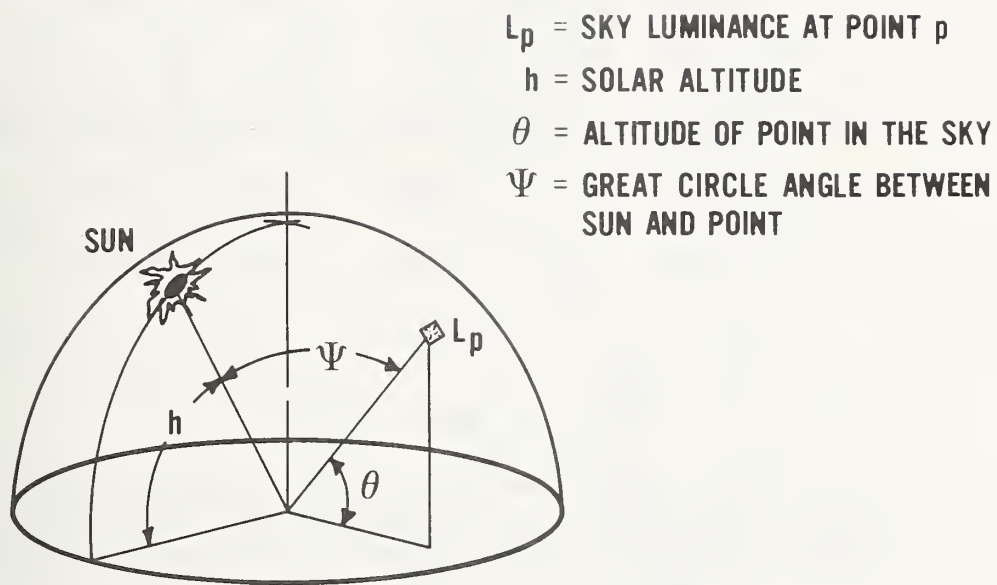


Figure 3.2 Sky dome with angles used in the sky luminance equations (angles in radians)

Table 1. Atmospheric Coefficients According to Dogniaux[12]
(Excluding h^3 Term)

		Rural Region $\beta = 0.05$		Urban Region $\beta = 0.10$		Industrial Region $\beta = 0.20$	
		a_0	a_1	a_0	a_1	a_0	a_1
Dry Air (Desert Climate) ↓ Humid Air (Tropical Climate)	$\omega^* = 0.5$	0.9361	0.0020	1.0329	0.0024	1.1399	0.0030
	$\omega = 1.0$	0.9093	0.0018	1.0206	0.0022	1.1499	0.0028
	$\omega = 2.0$	0.8727	0.0014	1.0074	0.0019	1.1698	0.0025
	$\omega = 3.0$	0.8547	0.0012	1.0019	0.0017	1.1833	0.0023
	$\omega = 4.0$	0.8460	0.0011	0.999	0.0016	1.1899	0.0022
	$\omega = 5.0$	0.8410	0.0011	0.998	0.0016	1.1968	0.0021

* ω given in centimeters of water

The data is bias toward the lower curve, which is to be expected since the NBS measurement station is in a semi-rural area where the air tends to be somewhat humid. This is confirmed by measurements taken 60 years ago in the same area [16].

The overcast luminance distribution model is based on the simplified Moon and Spencer model [17],

$$L_{P \text{ ovr}} = L_{Z \text{ ovr}} \frac{(1 + 2 \sin \theta)}{3}. \quad (3.6)$$

If this equation is integrated across the sky dome to obtain horizontal illuminance E_{vt} from the overcast hemisphere, the resultant integration can be solved for the luminance at angle θ as,

$$L_{\theta} = \frac{3}{7\pi} E_{vt} (1 + 2 \sin \theta) \quad (3.7)$$

for which the zenith luminance becomes,

$$L_z = \frac{9}{7\pi} E_{vt} \quad (3.8)$$

Equations 3.6 and 3.8 are, therefore, combined to provide $L_{P \text{ ovr}}$ as a direct function of E_{vt} under overcast conditions. This approach provides a substantially improved correlation with sky measurements (see chapter 6 on Validation) when compared to methods proposed by others.

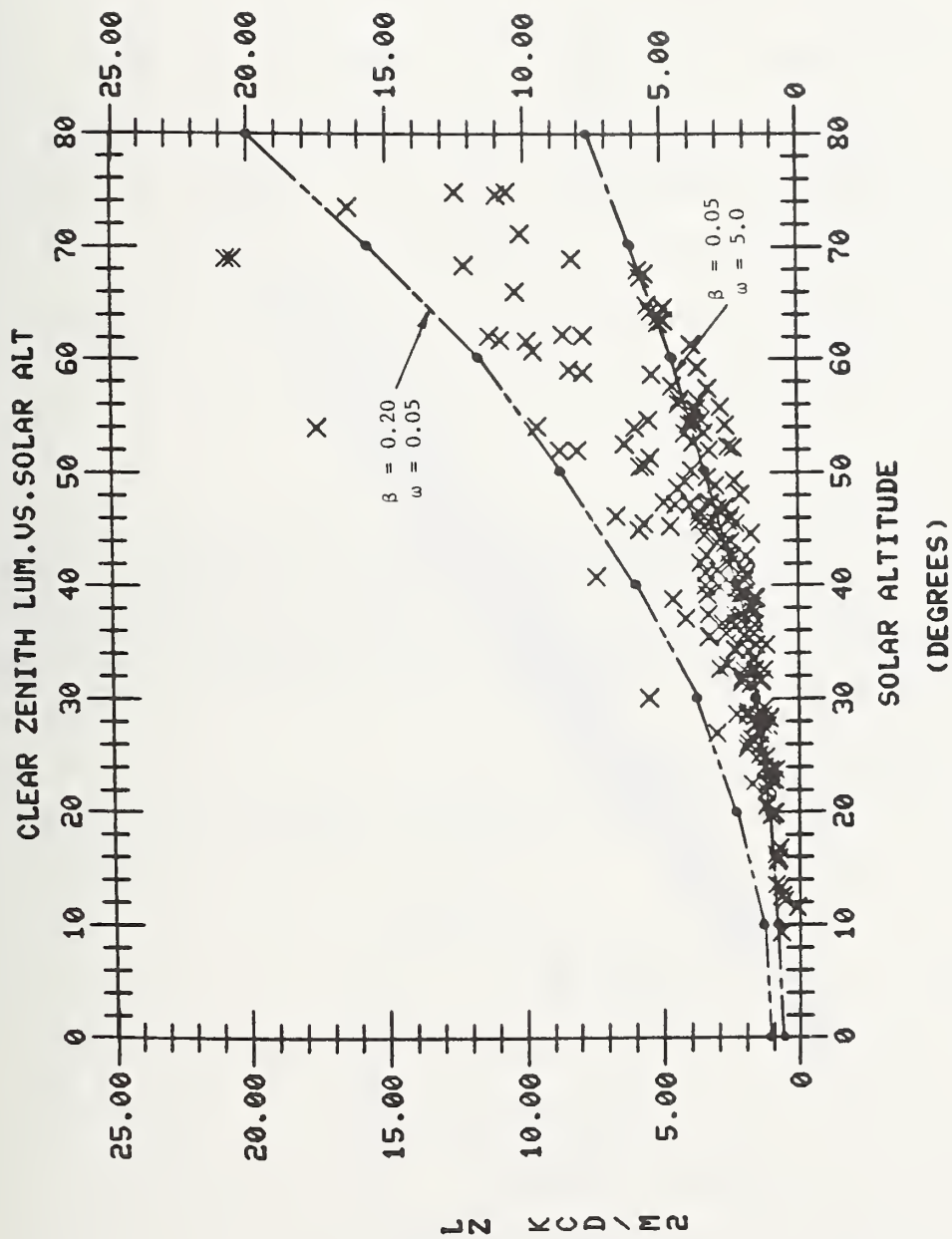


Figure 3.3 Clear sky zenith luminance as a function of solar altitude

3.4 PREDICTING HORIZONTAL ILLUMINANCE

Total and diffuse horizontal illuminance is obtained directly from knowledge of the total and diffuse solar radiation provided from the main program. Here a luminous efficacy approach is taken. Two equations are used,

$$E_{vd} = 111 E_{ed} \quad (3.9)$$

and

$$E_{vt} = (93 + 18 CR)E_{et} \quad (3.10)$$

where

E_{vd} = diffuse horizontal illuminance (lux);

E_{vt} = total (global) horizontal illuminance (lux);

E_{ed} = diffuse horizontal solar radiation (W/m^2);

E_{et} = total (global) horizontal solar radiation (W/m^2); and

$$CR = \frac{E_{ed}}{E_{et}}.$$

Equations 3.9 and 3.10 were also developed from the NBS measurements shown in figures 3.4 and 3.5. While it is possible to correlate E_{vt} with E_{et} using a single efficiency value (figure 3.5), it is more useful to express E_{vt} also in terms of the cloud ratio, which gives a smooth, continuous transition into equation 3.8 for $CR = 1.00$ (where $E_{vd} = E_{vt}$) while also covering more of the range seen in figure 3.5.

3.5 PREDICTING DIRECT BEAM ILLUMINANCE

For predicting the intensity of the direct normal sunlight the following equation is used,

$$E_{DN} = E_v SC \left[1 + 0.033 \cos \left(\frac{360 \times J}{365} \right) \right] e^{-a/\sin h} \quad (3.11)$$

where

E_{DN} = the direct normal beam illuminance;

$E_v SC$ = the solar illuminance constant;

J = the Julian date, from $J=1$ to $J=365$;

a = the atmospheric extinction coefficient; and

h = solar altitude.

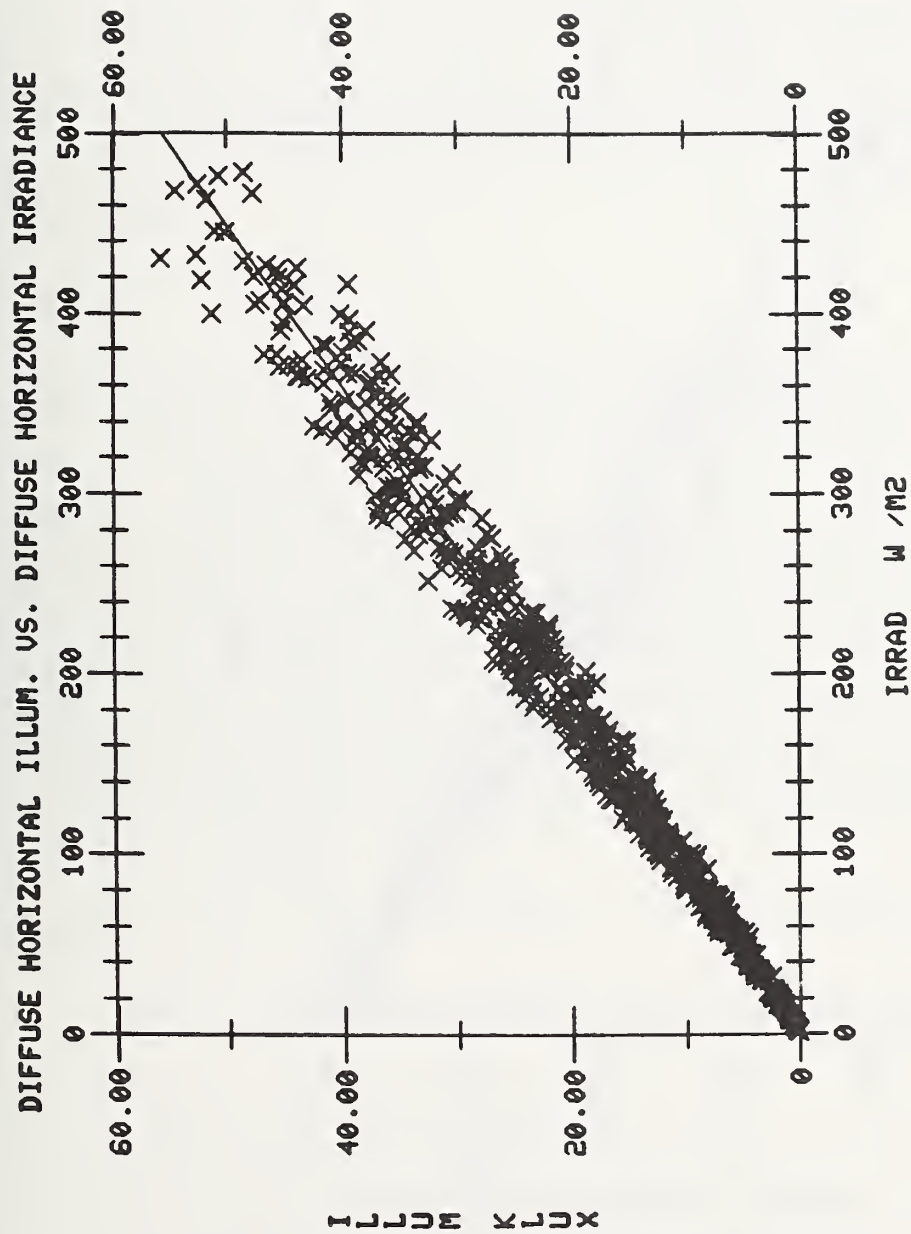


Figure 3.4 Diffuse illuminance as a function of diffuse solar radiation

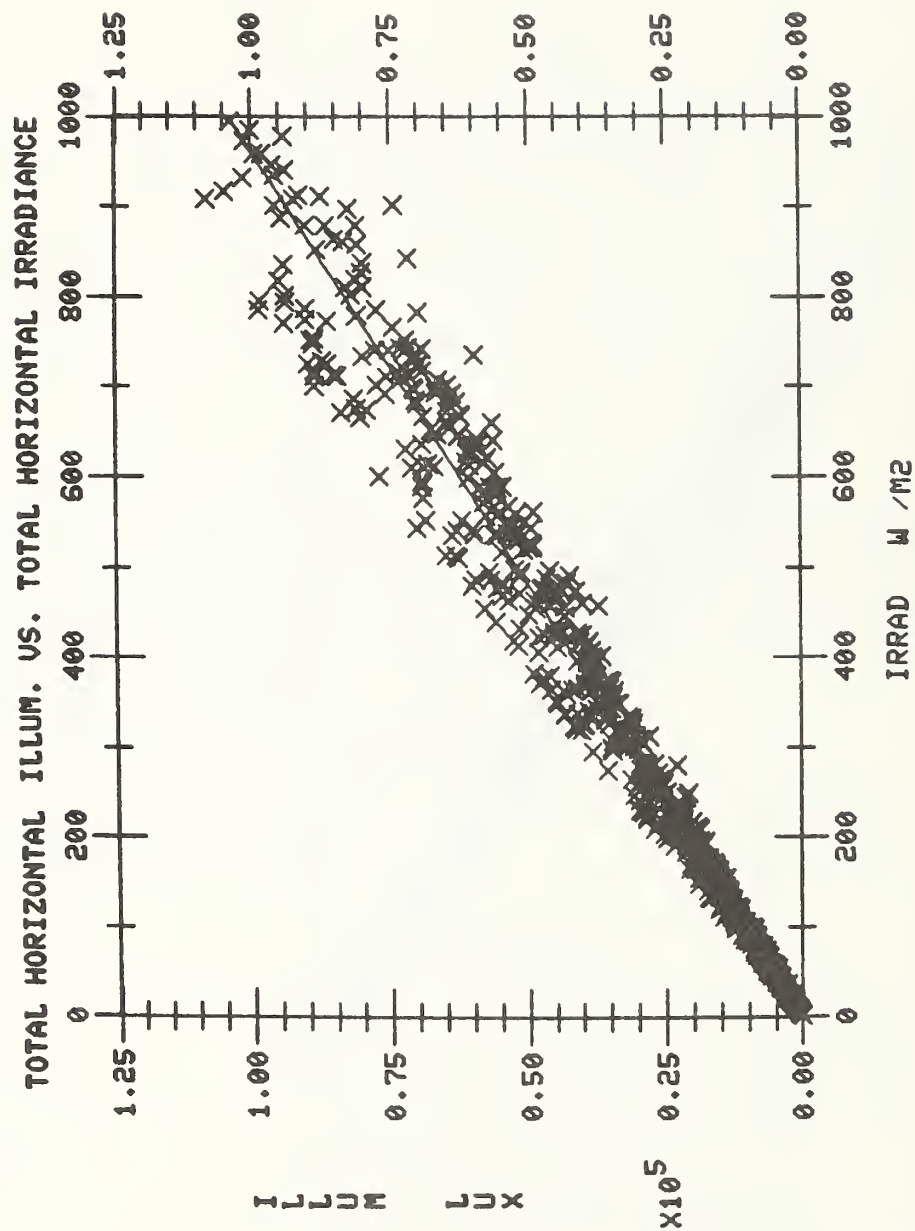


Figure 3.5 Total illuminance as a function of total solar radiation

The value for the mean extraterrestrial illuminance, $E_v \text{ SC}$, was obtained by integrating the ASTM [18] standard spectral irradiance as follows:

$$E_v \text{ SC} = K_M \int_{380}^{760} V_\lambda E_{e\lambda} d\lambda \quad (3.12)$$

where

K_M = the IES standard maximum spectral luminous efficiency, 683 lm/W [19];

V_λ = the IES standard spectral photopic eye response; and

$E_{e\lambda}$ = the ASTM standard spectral irradiance for the wavelength band, $d\lambda$.

The resultant value,

$$E_v \text{ SC} = 127.5 \text{ klx}$$

can be thought of as the daylighting equivalent of the solar constant, 1353 w/m². Measurements made both at NBS and elsewhere [20, 21] of the direct beam illuminance (figure 3.8) have been used to determine an average extinction coefficient for equation 3.7 of $a = 0.210$ for an unobstructed sun.

Others have measured the intensity of the direct beam with similar results [22]. Jones and Condit [20] extrapolated the Kimball and Hand data [16] to derive a zenith sun illuminance of 104.9 klx for the average condition between December and June sun. Moon [23] has also proposed a zenith value, which, when revised to agree with the currently recommended K_M , gives $E_{DN} = 108.1 \text{ klx}$. From equation 3.7 the predicted mean illuminance is 105.3 klx, which agrees with Jones and Condit by within one percent and with Moon by within three percent. Similarly, Elvegard and Sjöstedt [24] fit a curve through their Swedish and Finnish data and reported a constant extinction coefficient of 0.231, a value that would cause the direct solar illuminance to be only slightly lower than predicted for equation 3.10.

The final form of the equation, therefore, for the instantaneous sun illuminance on a horizontal plane becomes,

$$E_{vs} = E_{DN} \cdot \sin h \cdot \xi_{clr} \quad (3.13)$$

where,

E_{vs} = the horizontal solar illuminance;

ξ_{clr} = the clear sky fraction (see Section 3.2).

The $\sin h$ term corrects for the flux on the horizontal plane, and ξ_{clr} corrects for the loss in intensity due to partly cloudy conditions.

*Facing page: Measuring the interior daylight
illuminance within a room.*



4. THE RMLITE ROUTINE

4.1 CAPABILITIES

RMLITE computes the interior illuminances on a horizontal workplane 0.76 m (2.5 ft) above the floor. The cumulative effect of multiple windows or skylights is recorded to give illuminances at user selected points within the room. It should be noted, however, that this routine is room specific and surface specific, meaning that the fenestration must be on one of the room surfaces, and that the illuminance positions must be within a defined room configuration. In some energy programs this might cause problems. For cases where the main energy program is not room specific, simplifications are possible in the RMLITE routine. This is discussed further under Subroutine Interfacing (Appendix C).

4.2 PREDICTING INTERIOR DAYLIGHT ILLUMINANCES

The interior daylight prediction technique is a simplified radiant flux procedure. The fenestration, room surfaces, and exterior surroundings are divided into sufficiently small surface elements where each element is either a primary or secondary source of light with a luminous exitance M^* . In the most general case, the expression is:

$$E_p = \frac{1}{\pi} \int_f \int_m \frac{M \cos \theta \cos \psi}{D^2} df dm \quad (4.1)$$

for the illuminance E_p from direct light sources above the workplane such as the portion of sky viewed through the fenestration (figure 4.1).

Equation 4.1 can also be used to compute the illuminances on the interior surfaces, which then become sources of secondary or reflected light. The more rigorous lighting computer programs generally make extensive use of radiant transfer [25] to obtain a much more refined solution, but such rigor is not necessary for this type of analysis.

Simplification can be done if the integration is made for generic types of geometric configurations. Using the integrated equations of Higbie [26], and more recently Pierpoint and Hopkins [27], a direct solution can be achieved for equation 4.1 provided the luminance of the surface is assumed uniform. Furthermore, subdividing the room and fenestration surfaces into a minimum number of surfaces further reduces the number of computations. Both strategies are used by the RMLITE routine and, as will be shown, provide a fast, yet in most cases sufficiently accurate daylighting algorithm.

4.3 PREDICTING ILLUMINANCES FROM PRIMARY LIGHT SOURCES

4.3.1 Diffuse Light From Vertical Windows

For the diffuse illuminance from the sky on a horizontal surface due to a vertical window, Higbie's perpendicular surface geometry equation is used,

$$E_p = \frac{L}{2} \left[\tan^{-1} \frac{m}{a} - \left(\frac{a}{\sqrt{a^2 + f^2}} \right) \tan^{-1} \left(\frac{m}{\sqrt{a^2 + f^2}} \right) \right] \quad (4.2)$$

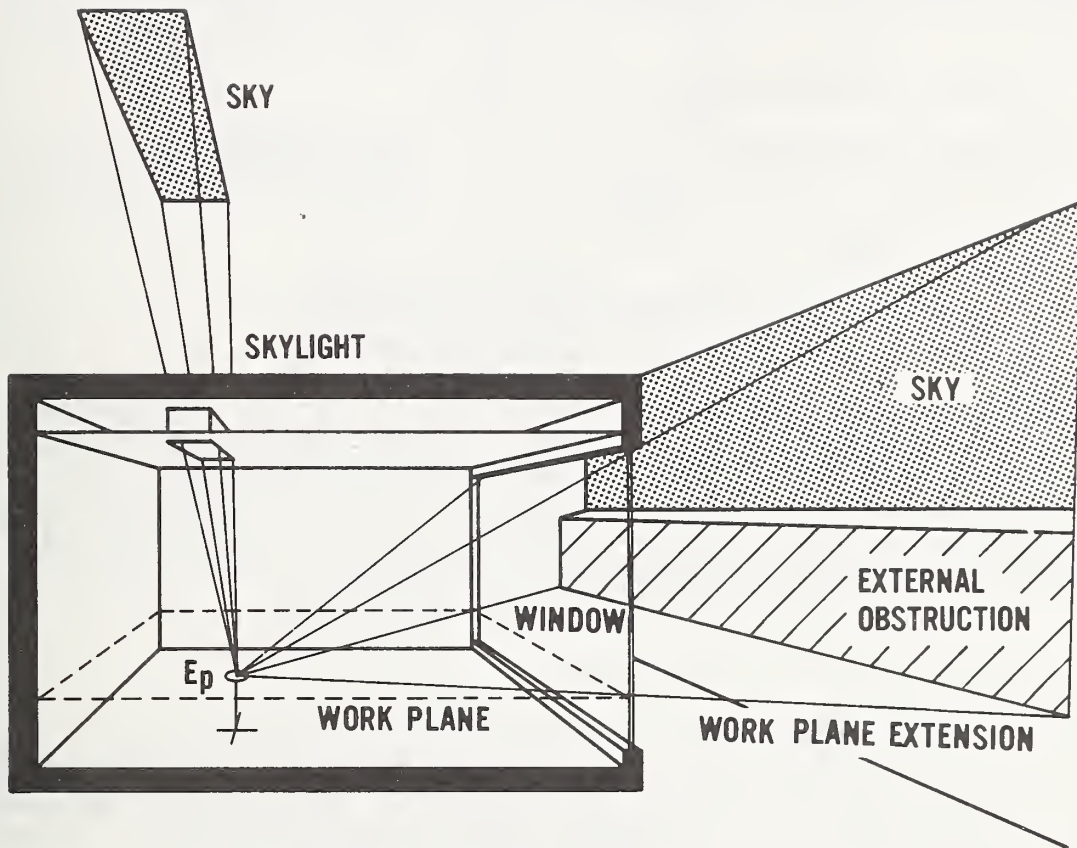
where,

E_p = workplane illuminance at point p;

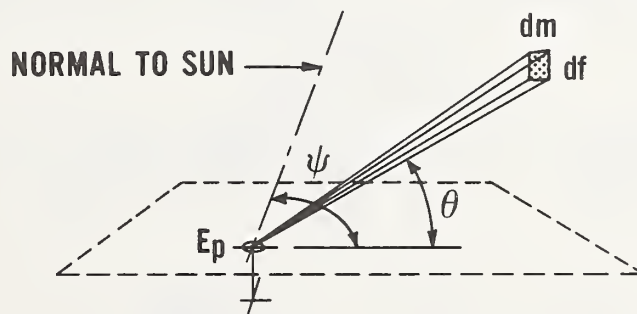
L = centroid luminance of sky patch seen through opening mf; and

a, m, f = distances as shown in figure 4.2.a.

* Luminous exitance can be assumed equal to source luminance if an approximate lambertian surface is assumed; if so, $M = \pi L$, where L is the source luminance.



a) The daylight contributors to the illuminance at point p



b) How the daylight is modeled

Figure 4.1 Predicting the interior illuminance E_p at point p

E_p is given in lux when a , m , and f are in meters and L in nits (cd/m^2); E_p is in footcandles when a , m , and f are in feet and L in footlamberts. Lastly, superposition is used to locate this surface element anywhere on the wall.

4.3.2 Diffuse Light From Horizontal Skylights

For the diffuse illuminance from the sky on a horizontal surface due to a horizontal skylight, Higbie's parallel surface geometry equation is used,

$$E_p = \frac{L}{2} \left[\frac{f-a}{\sqrt{c^2 + (a-f)^2}} \tan^{-1} \left(\frac{m}{\sqrt{c^2 + (a-f)^2}} \right) \right] \quad (4.3)$$

where the geometry is shown in figure 4.2.b.

The skylight luminance L deserves a special note. For the skylight units with both transparent inner and outer glazing, L is the centroid sky luminance. However, when either outer or inner glazing is translucent, which is normally the case, L becomes the total exterior horizontal exterior illuminance E_{vt} (from sun and sky) multiplied by the net transmittance. The net transmittance includes the transmittance of both glazings, the dome effects, and the wall effects; it can be obtained from Appendix A [28].

4.3.3 Diffuse Light From Clerestories

The direct skylight admitted through the vertical glazing in a clerestory is treated as if coming from a remote vertical window (see 4.3.1), except that checks are made for those illuminance points along the workplane that would be obstructed from view of the clerestory fenestration (figure 4.3). The reflected light from roof and the sky onto the sloped clerestory ceiling is modeled using the Pierpoint and Hopkins equation,

$$E_p = \frac{L}{2} \left[\begin{aligned} & \frac{x}{\sqrt{x^2 + z^2}} \tan^{-1} \frac{m \sqrt{x^2 + z^2}}{x^2 + y^2 + z^2 - ym} \\ & + \frac{f \cos \psi - x}{\sqrt{x^2 + z^2 + f^2 + 2fG}} \tan^{-1} \frac{m \sqrt{x^2 + z^2 + f^2 + 2fG}}{x^2 + y^2 + z^2 - ym + f^2 + 2fG} \\ & + \frac{y \cos \psi}{\sqrt{y^2 + H^2}} \tan^{-1} \frac{f \sqrt{y^2 + H^2}}{y^2 + H^2 + G^2 + fG} \\ & - \frac{(y - m) \cos \psi}{\sqrt{(y - m)^2 + H^2}} \tan^{-1} \frac{f \sqrt{(y - m)^2 + H^2}}{(y - m)^2 + H^2 + G^2 + fG} \end{aligned} \right] \quad (4.4)$$

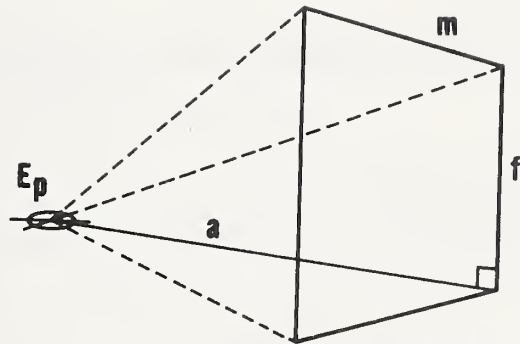
where,

$$G = z \sin \psi - x \cos \psi$$

and

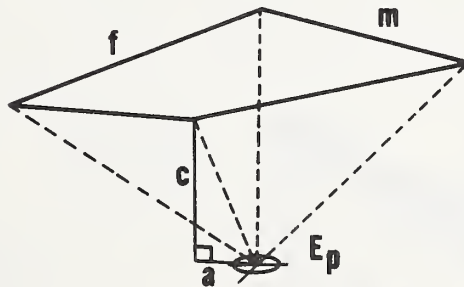
$$H = z \cos \psi + x \sin \psi$$

The geometry is illustrated in figure 4.2.c. The luminance in this case is the centroid exitance of the surface, found by the product of the ceiling reflectance and the illuminance at the ceiling centroid.



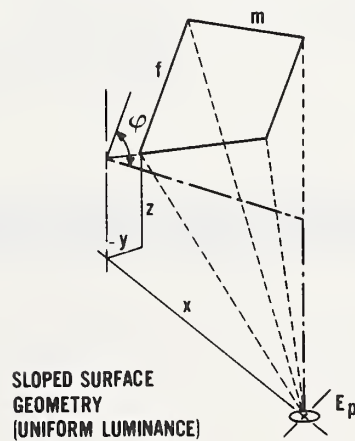
**RIGHT ANGLED SURFACE GEOMETRY
(UNIFORM LUMINANCE)**

Figure 4.2.a



**PARALLEL SURFACE GEOMETRY
(UNIFORM LUMINANCE)**

Figure 4.2.b



**SLOPED SURFACE
GEOMETRY
(UNIFORM LUMINANCE)**

Figure 4.2.c

Figure 4.2 Geometric configurations for equations 4.2 - 4.4

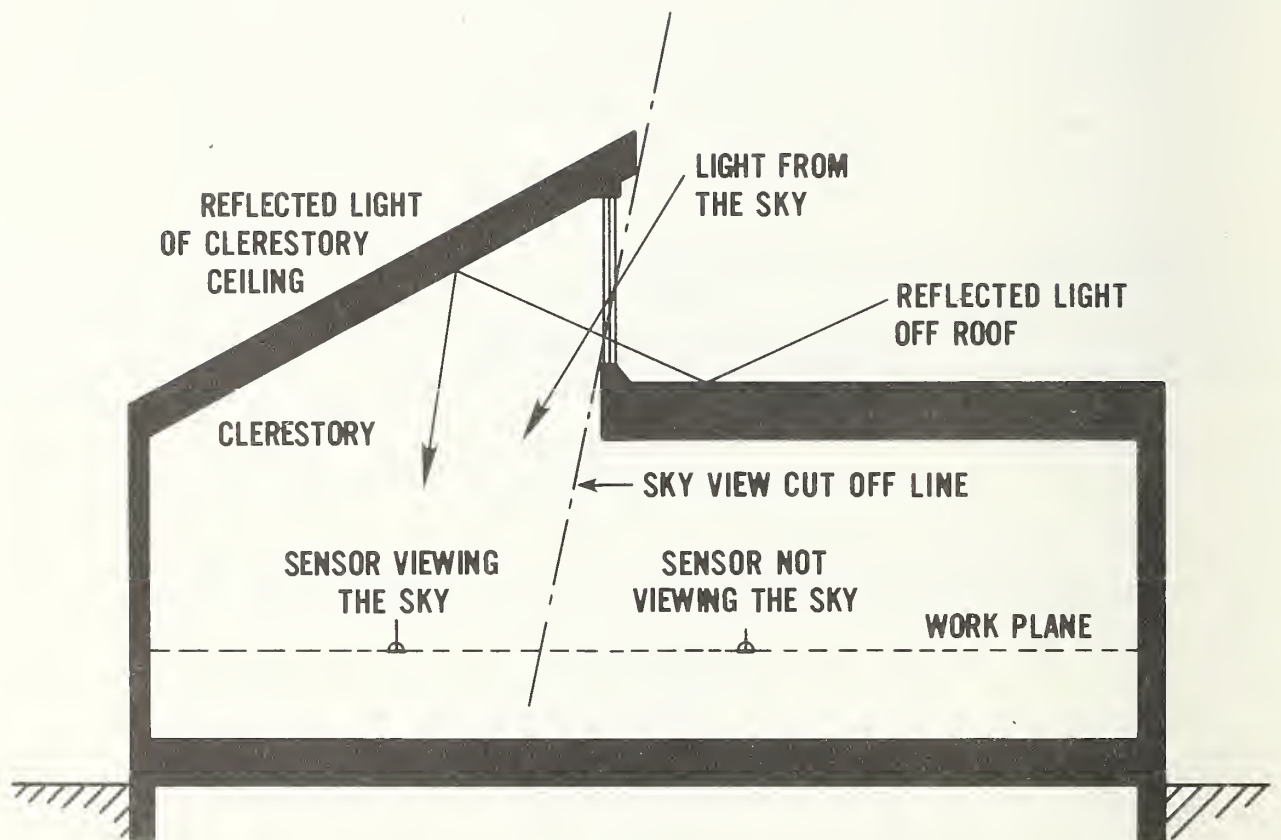


Figure 4.3 Clerestory illuminance technique

4.4 PREDICTING ILLUMINANCES FROM SECONDARY LIGHT SOURCES

4.4.1 Light From External Obstructions

External obstructions, such as surrounding buildings, are modeled as diffuse light sources with a uniform luminance. This luminance is obtained by multiplying the sky luminance for that obstructed region of the sky by the obstruction reflectance ρ_x . Geometrically, the obstructions are assumed to be simple vertical projections above the workplane running continuously in the horizontal direction (figure 4.4). It is possible to simulate external obstructions in a more rigorous way, yet because actual size and surface reflectance are rarely (if ever) known, it would be difficult to justify the increased complexity.

4.4.2 Light From the Ground

The ground reflected light is found by first obtaining the uniform ground luminance, which is the product of the total horizontal illuminance, E_{vt} , and the ground reflectance. Assuming that the ground surface is an infinite horizontal plane, the parallel surface equation is used to project ground light onto interior horizontal surfaces (the ceiling for example); the perpendicular surface equation is similarly used for vertical wall surfaces.

Light reflected off the roof onto the sloped clerestory ceiling surface is treated in like manner. Here the Pierpoint and Hopkins equation is used to obtain the illuminance at the center of the interior sloped surface due to the sky and the roof, which in turn, is then reflected into the room.

4.4.3 Light Interreflected Within Room

The multiple reflections and interreflections of light flux within a room is normally the most time consuming part of the most large lighting programs. Analytically, it is the most complex. Not only must equation 4.1 be applied for each incremental area within the room due to each source of light, but this must be done repetitively as these areas illuminate to become themselves sources of secondary light. Yet such an approach is necessary only if a rigorous solution is sought.

A simpler technique is to subdivide the room into only a few surfaces, such as the six enclosure surfaces. Obviously, averaging the luminance over these larger surfaces will be a less exact procedure. However, the fraction of the total illuminance due to interreflected light is normally quite low, thus, minimizing the impact on the total illuminance at a given point. Furthermore, due to uncertainties in the correct values for hemispherical-directional reflectance, and noting that internal obstructions on the walls and within the room normally exist, it is difficult to justify substantial time on the interreflected light calculation.

In some ways the interreflected model used in RMLITE is similar to the split flux method [29, 30] which subdivides the room into two hemispherical elements, but overcomes one of its weaknesses by being more general and applicable to rooms with fenestration other than windows. The six surface model should also

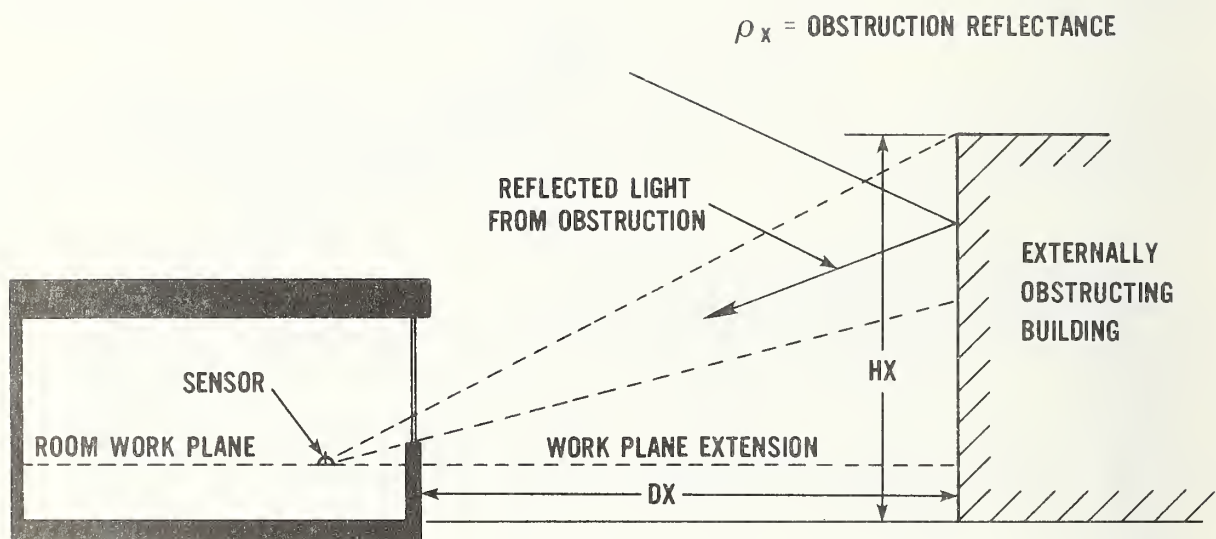


Figure 4.4 Light from external obstructing buildings

be slightly more accurate. Once the initial light flux is determined on each of the six surfaces, multiple interreflections are accounted for by assuming the room acts as an Ulbricht integrating sphere, an assumption that is valid for wall reflectances approaching the ceiling reflectance and room depths less than twice the ceiling height.

Dressler [31] found that if the wall surfaces act as diffuse lambertian reflectors, then the first reflected flux within the room can be expressed as,

$$\Sigma F_i = F_1\rho_1 + F_2\rho_2 + \dots + F_n\rho_n \quad (4.5)$$

where F_n is the initial flux on surface n , ρ_n is its diffuse reflectance, and ΣF_i is the sum of the first reflected flux. The multiple reflected flux then becomes,

$$\Sigma F_i (1 + \rho_{ave} + \rho_{ave}^2 + \rho_{ave}^3 + \dots) = \frac{\Sigma F_i}{1 - \rho_{ave}} \quad (4.6)$$

Since the illuminance of the Ulbricht sphere is total flux over the total area, the interreflected illuminance becomes,

$$E_{ref} = \frac{(F_1\rho_1 + F_2\rho_2 + F_3\rho_3 + \dots + F_n\rho_n) + F_s\rho_f}{(1 - \rho_{ave}) A_t} \quad (4.7)$$

where

- $F_n = E_n A_n$ (for each room surface)
- $F_s = E_s A_s$ (for the projected sunlight)
- ρ_f = the reflectance of the floor
- ρ_{ave} = the average reflectance of all surfaces
- A_t = the total area of all surfaces
- A_n = the area of surface n
- A_s = the area of the sun patch rhomboid
- E_n = the centroid illuminance of surface n
- E_s = the sun patch illuminance from equation 3.13.

The initial centroid illuminance E_n for each surface is found by equations 4.2 through 4.4.

By letting $n = 6$ and solving equation 4.5, the inter-reflected daylight is obtained in a fraction of the time it would require other more rigorous models.

4.5 PREDICTING DIRECT SUNLIGHT

The model to determine the contribution of direct sunlight is fairly straightforward. The rhomboidal projection of the fenestration on the work-plane is first determined and a check is made whether an illuminance point is within one of these patches of sunlight (figure 4.5). If so, the direct beam illuminance E_s is added to the existing workplane illuminance, after being corrected for glazing angle transmittance and cosine angle between the work-plane and the sun.

4.6 MODELING GLAZING TRANSMITTANCE

There are two types of glazing transmittance used, the angular dependent transmittance, τ_D , for direct sunlight, and the hemispherical transmittance τ_d , for diffuse sky light. For flat fenestration the latter is assumed constant. The former, τ_D , varies with the angle between the surface normal and the sun angle, ψ , according to the expression [32],

$$\tau_\psi = 1.018 \tau_0 \cos \psi (1 + \sin^3 \psi) \quad (4.8)$$

where τ_0 is the visible transmittance value normally obtained from manufacturer's data.

For domed skylights, the curvature of the upper dome has been found to affect the transmittance of both the direct and diffuse daylight [33]. Although the aspect ratio of the dome, incident angle, and variations in thickness of the glazing material will cause variations in the direct transmittance, τ_D , the range is within approximately 10 percent of τ_0 for solar altitudes above 20 degrees [28]. Thus, a single value is used for the direct transmittance. On the other hand, τ_d requires correction for well losses, which combine to give a single effective transmittance, τ_{eff} . While it is possible to incorporate all the transmittance correction factors into the computer model, it is far easier and probably more practical to allow this value to be computed externally (see Appendix A).

4.7 MODELING OVERHANGS AND SIDE FINS

Overhangs and side fins are accounted for by adjusting the effective window area according to the viewing obstruction angle. For overhangs, an effective window height is computed and used as if this were the actual height. Similarly, side fins adjust the window width to provide an effective window size as seen by point p. Since each correction is specific to the illuminance point under consideration, these adjustments are done for each point.

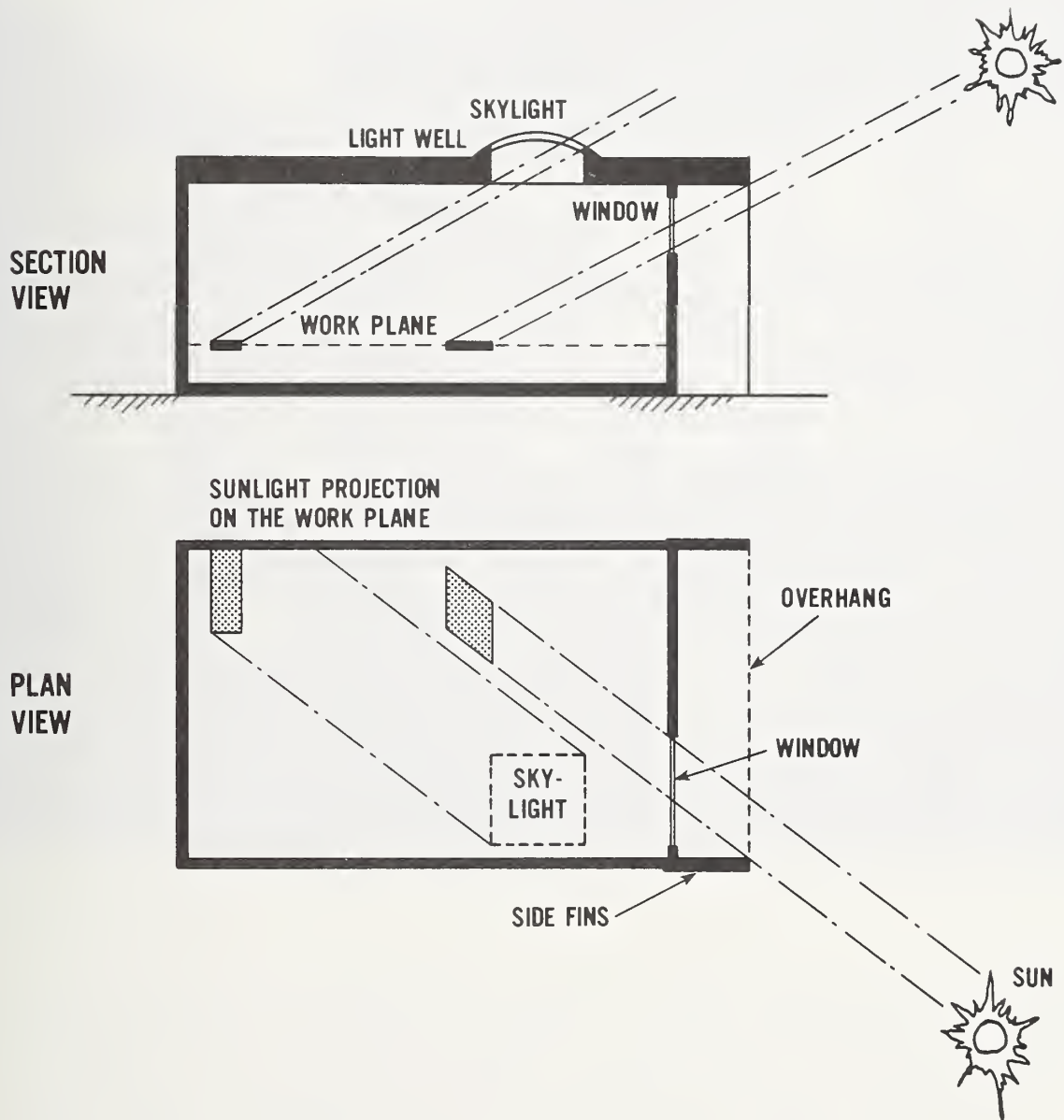


Figure 4.5 Sunlight projection within room

*Facing page: Supplementing daylighting with
incandescent sources to provide
a constant illuminance level.*



5. THE LLOAD ROUTINE

Once the illuminance is obtained at a point within the room, it is the lighting load routine LLOAD which develops an associated power load for use in the main building energy program. But a note should be made here. The daylight illuminance at a position on the workplane means nothing in terms of energy unless some type of control system recognizes this intensity and can respond by changing the power requirement of the lighting system. This is usually accomplished through the use of a photocell. The response strategy could be either switching or dimming; and the lighting system sensitive to this point illuminance could be a single luminaire, a bank of luminaires, or all the luminaires within the room. Since photocells are normally not located on the workplane,

it is important to explain that the lighting system must be balanced once installed to meet a specified workplane illuminance and, therefore, the point where balancing is done becomes the illuminance point.

The LLOAD subroutine is not a lighting design tool but an analysis tool. Information must be supplied to the program stating the full lighting power load controlled by each photocell. On so doing, a completely general model is provided for modeling almost any type of lighting layout. Figure 5.1 will help explain this. Ambient and task lighting is shown where three illuminance points control three banks of general illumination, and one controls a task luminaire. As far as the daylighting model is concerned, the only important information necessary is the position directly below the photocell, the full connected power which will respond to the sensor, the setpoint illuminance, and the dimming strategy.

Four dimming strategies are offered. A simple on/off strategy shuts the connected power off once the setpoint illuminance is met by daylight. The second strategy, half-on/half-off step-down, shuts off half the connected power at half the prescribed illuminance, and the remainder after this illuminance is exceeded. The third strategy is a continuous dimming technique where the power is proportionally adjusted to follow a typical performance curve [34,35], but remains at the minimum power level when supplemental light is no longer necessary. The fourth is similar to the third except it allows the luminaires to shut off completely once the minimum power is reached. The continuous dimming strategies assume a simple linear relation between the percent supplemental light, $\%E_{sup}$, and the percent power required, $\%W_{req}$,

$$\%W_{req} = \xi (\%E_{sup}) + \chi \quad (5.1)$$

where ξ and χ are specified lighting control coefficients. If such coefficients are not available, the following default values are assumed for a generic system,

$$\begin{aligned} \xi &= 0.70 \\ \chi &= 0.30. \end{aligned}$$

Equation 5.1 is a simplified expression representing the generic curve for the dimming performance of a fluorescent ballast system (figure 5.2). For other types of lamp systems, such as high pressure sodium, appropriate values for ξ and χ can be substituted.

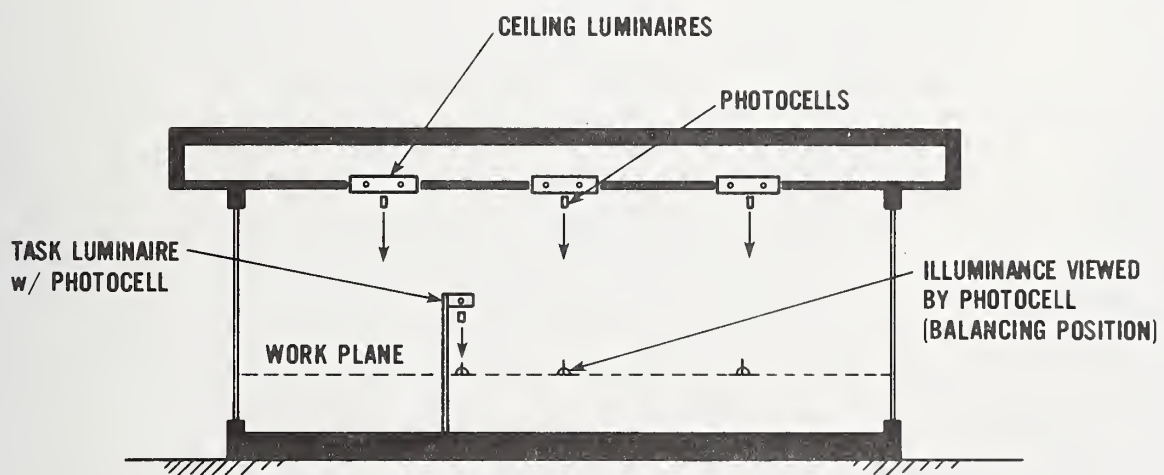


Figure 5.1 Task/ambient and general lighting layouts as viewed by program

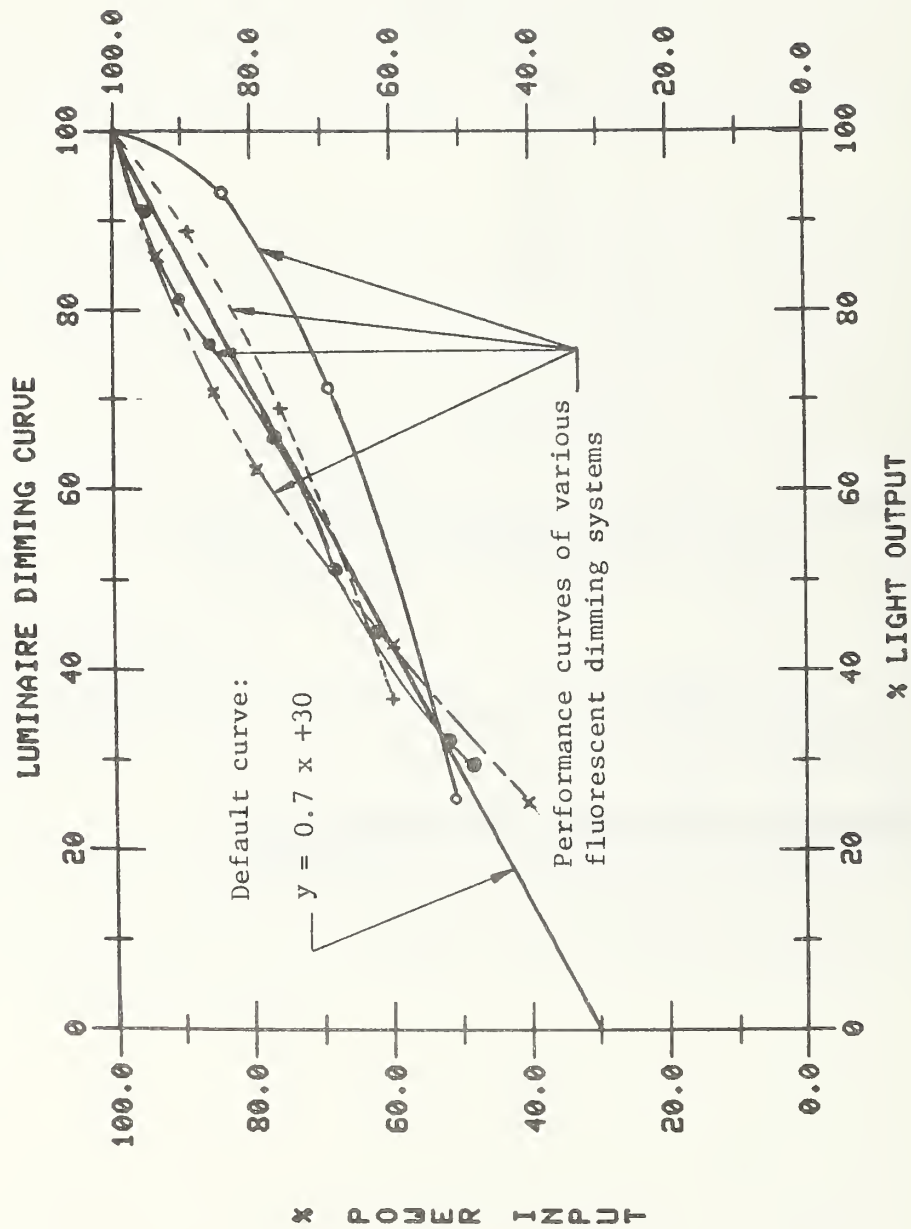
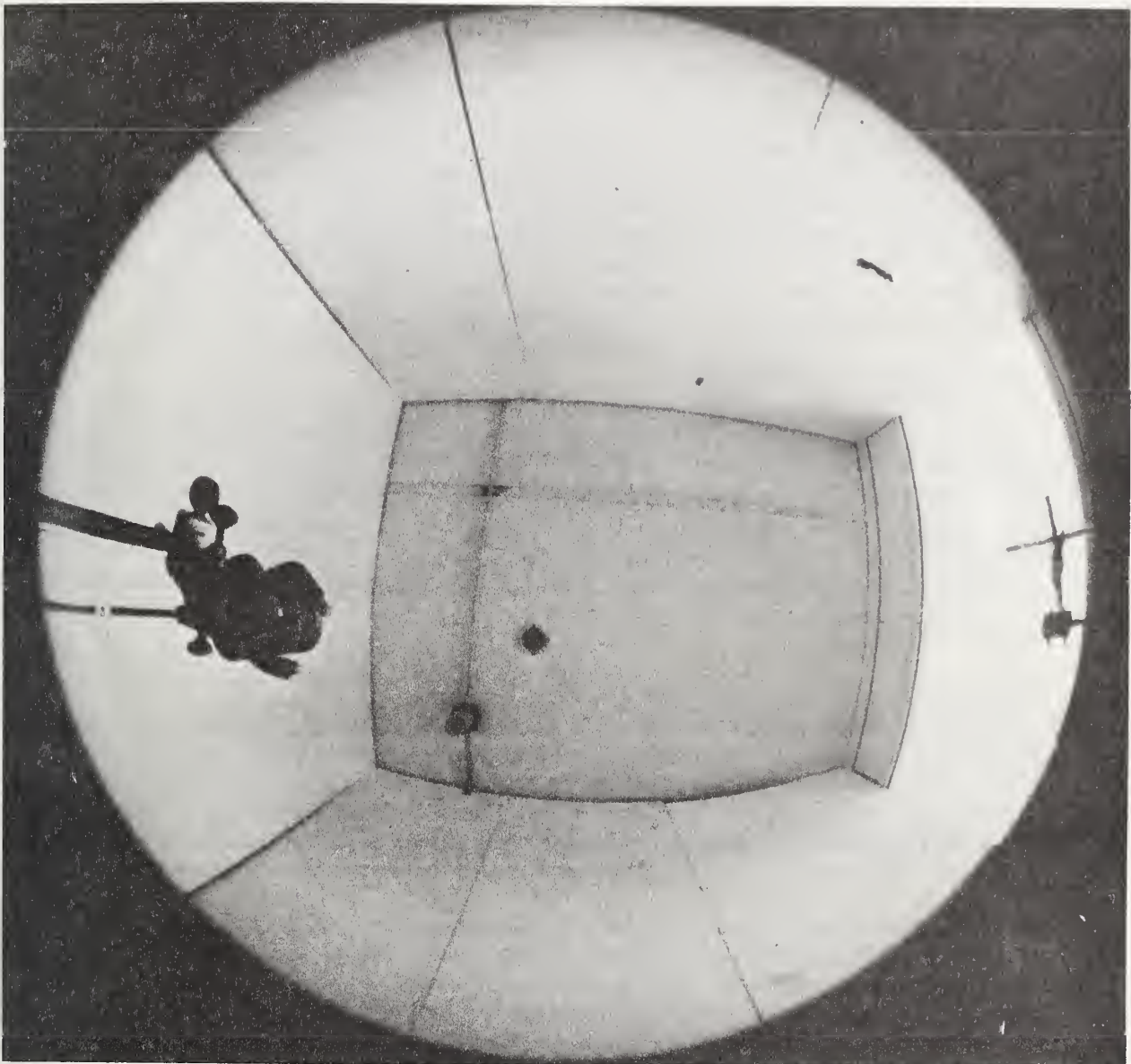


Figure 5.2 Dimming curve of luminaire dimming system used as default along with similar curves of various manufacturers



Caption: Validation measurements within a full scale room

6. VALIDATION

Inherent in any prediction technique is the need for validation against real-case conditions. Although it is sometimes possible to show a sufficient correlation by simply conducting a relative check with field measurements, such simplification can be very misleading. The case is particularly true with the validation of computer models. Some models simulate some conditions better than others, and as with all prediction techniques, the accuracy of the assumptions in the model and the accuracy of the input variables can often remain uncertain. Furthermore, daylighting measurements must be done with extreme care and should be based on a series of like measurements in order to assess the uncertainty of each measured quantity.

To control these characteristic uncertainties, evaluating the accuracy of the DALITE model was done in stages, by first carefully establishing the test conditions for comparisons, and then by conducting step-by-step validation of each of the major algorithms used within the program. The sky model was compared against hourly measurements of sky luminance, sky illuminance, and solar radiation; the room illuminance model was compared against measurements made in two full-scale test rooms and in mock-up models; and the lighting load model was checked against laboratory tests of luminaire dimming and step-down performance. Where comparable measurements by others were available, a check with their data was also done. The result is an overall validation, showing both the strengths and weaknesses of the daylighting model.

6.1 VALIDATION OF THE SKY MODEL

SKYLUM, the subroutine that generates the hourly sky luminance, sky illuminance, and direct sun illuminance, was validated against sky measurements made at the National Bureau of Standards in Gaithersburg, MD (latitude $38^{\circ} 5'$, longitude $77^{\circ} 0'$). The NBS data were from a series of days taken from more than two years of sky measurements. The reference sky data were selected from measurements known to be correct, and were chosen to provide good hourly data of clear skies, overcast skies, partly cloudy skies, summer conditions, winter conditions, and fall/spring conditions.

6.1.1 Validation of Sky Luminance

There are two basic parts to the sky luminance algorithm that need to be validated: the sky luminance distribution and the zenith luminance. Also, since a phasing technique is used to obtain intermediate sky condition based on the mix between the clear and overcast sky, both the validity of the phasing technique and the modeling of the clear and overcast skies must be substantiated.

The luminance distribution plots are illustrated in figures 6.1 and 6.2 of the clear and overcast skies respectively. Figure 6.1 shows the validity of the clear sky distribution model, particularly for sky regions away from the sun where the sky luminances are below $2,000 \text{ cd/m}^2$. It should be noted, however, that figure 6.1 is not a validation of the Kittler clear sky equation, but rather a comparison showing the ability this equation has in estimating the luminances in the real (not a standardized) clear sky. Likewise, figure 6.2 represents the correlation of the overcast luminance distribution with measured luminances. The four different symbols represent the 42 degree luminance at the four cardinal orientations. If the sky were perfectly uniform with respect to orientations, the symbols would coincide; and if the distribution matched the simulated distribution perfectly, the plot would fall on the solid line. Given the variableness in instantaneous sky conditions, both distribution models appear to perform reasonably well.

The zenith luminance correlations shown in figures 6.3 and 6.4 plot the sky model's ability to predict the sky luminance at the zenith, which is normally the reference value used to obtain absolute luminances once the luminance distribution is known. Figure 6.3 compares the validity of the clear sky zenith equation while also revealing the stability in the sky conditions. In a

similar way, a general agreement is also illustrated in figure 6.4, but with an expected increase in scatter due in part to the variability of the overcast sky.

6.1.2 Validation of Exterior Horizontal Illuminance

A comparison of calculated exterior horizontal illuminance is shown against comparable measurements in figure 6.5. The data represents a substantial set of measurements for a wide range of sky conditions and cloud type and shows a good linear agreement. The correlation shows agreement both in the clear summer months (above 60,000 lux) as well as the winter months (below 60,000 lux).

6.1.3 Validation of Direct Beam Illuminance

Figure 6.6 is used to validate the direct beam illuminance algorithm. The sunlight algorithm for the winter solstice (Julian date = 321) and summer solstice is compared against measurements made both at NBS and elsewhere within the United States [36]. Unfortunately, much of the data recorded elsewhere was not separated by season, and it appears as though there is a slight seasonal dependence, but this is only a second order affect for lower solar angles. The equation is seen to capture the seasonal variation and exhibits a good fit to the measured data.

6.2 VALIDATION OF THE ROOM ILLUMINANCE MODEL

The interior daylight illuminance model was validated using measurements from two full-scale test rooms and two scale-model test rooms. Because the interior prediction routine incorporates all the other subroutines, this validation represents the overall performance of the daylighting program. Furthermore, since the collective set of subroutines can simulate many daylighting scenerios, it was desirable to evaluate several room, fenestration, and sky conditions.

The physical characteristics of the four test rooms used in the validation work are given in figures 6.7 and 6.8. The four rooms provide measurement data for rooms of different dimensions, wall reflectances, and fenestration types and orientations. Although not all possible combinations were explored, the ones illustrated appear representative; scale model measurements facing east and west and with different glazing areas show similar results. The two scale-models (test room No. 1 and No. 2) and one of the full-scale rooms (test room No. 3) had workplane illuminance recorded each hour along with the other hourly measurements of sky luminance, sky illuminance, and horizontal solar radiation. The fourth test room was instrumented in a slightly different way, with independent measurements taken every five minutes and catalogued according to depth from the fenestration. These latter measurements could be compared to determine the amount of relative uncertainty in the daylighting measurements. Hourly profiles of both calculated and measured illuminance in the scale models are shown in figures 6.9, 6.10, and 6.11 representing the overcast, partly cloudy, and clear sky conditions respectively. All three figures show good agreement for all sky conditions, particularly under the clear and overcast sky. Figure 6.11 also shows the successful modeling of the direct sunlight. In a similar way, hourly values are compared for the full-scale room No. 3, but with a full range of sky conditions (cloud ratios) in figure 6.12.

The measurements performed in test room No. 4 were done separately from the others. Special care was taken to obtain precision measurements of instantaneous room and sky conditions and to provide exact input information for the prediction routine. In this way a band of the uncertainty in the data can be noted. Figure 6.13 is an overall comparison plot of all the measurements (excluding the clerestory measurements) for room No. 4 and shows that, in general, the daylight program tends to overpredict slightly at deeper room depths and to underpredict slightly near the fenestration; however, given the uncertainty of each measured quantity, the correlation is still quite good.

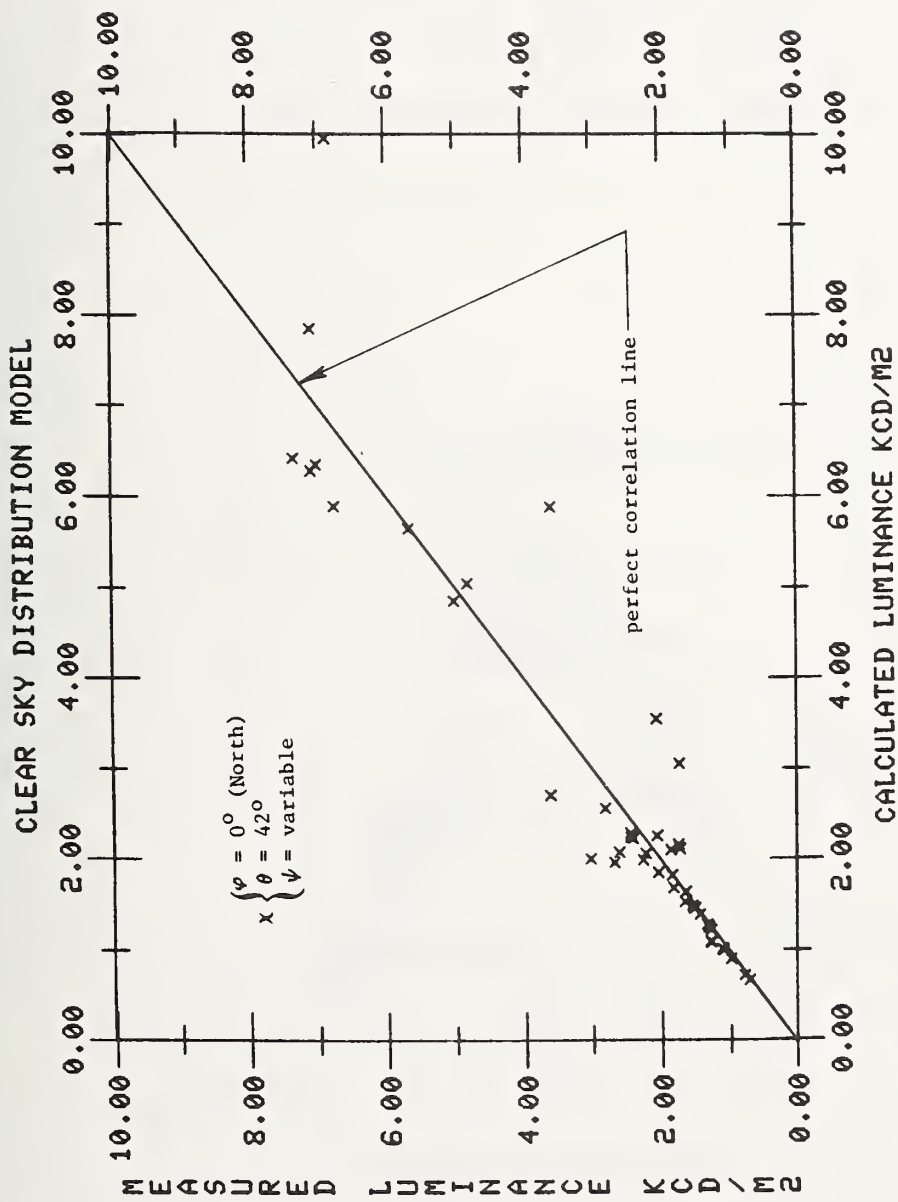


Figure 6.1 Measured sky luminance versus calculated luminance using the clear sky distribution model

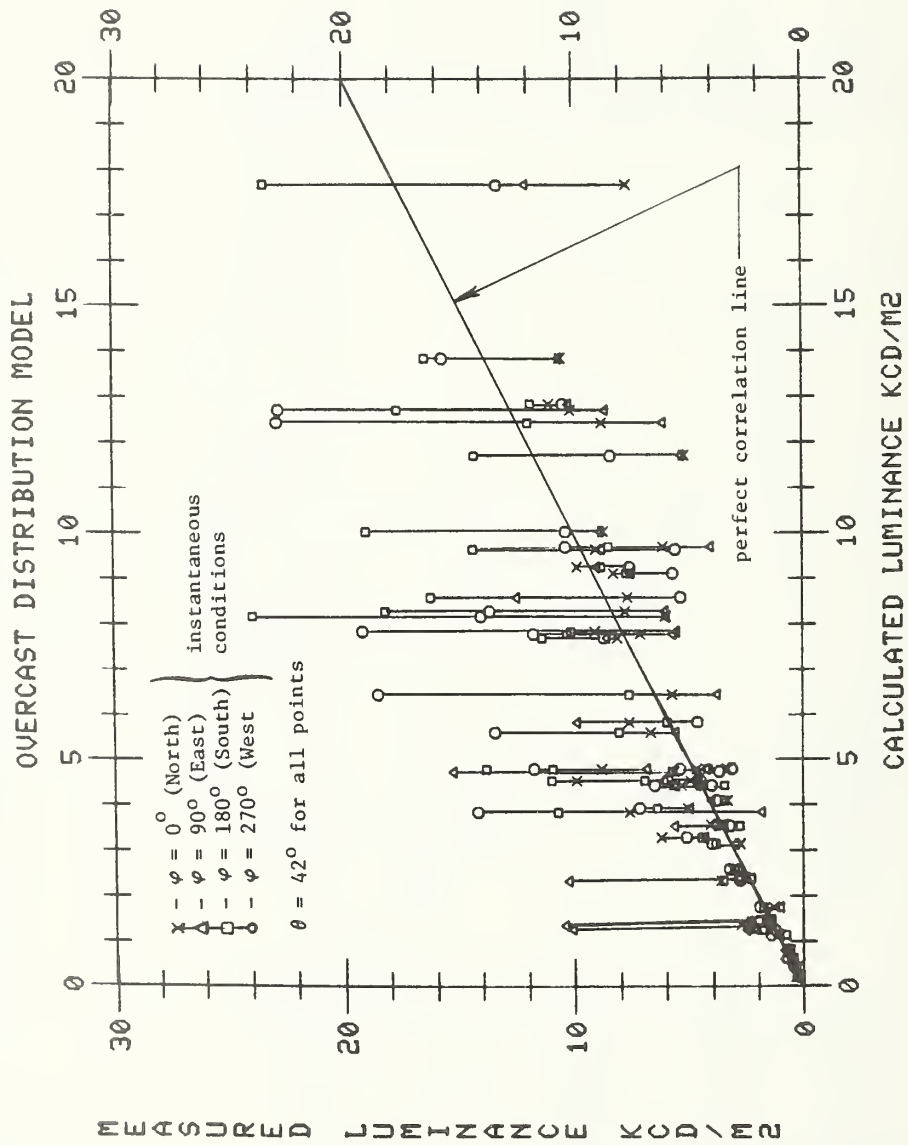


Figure 6.2 Measured sky luminance verses calculated luminance using the overcast sky distribution model

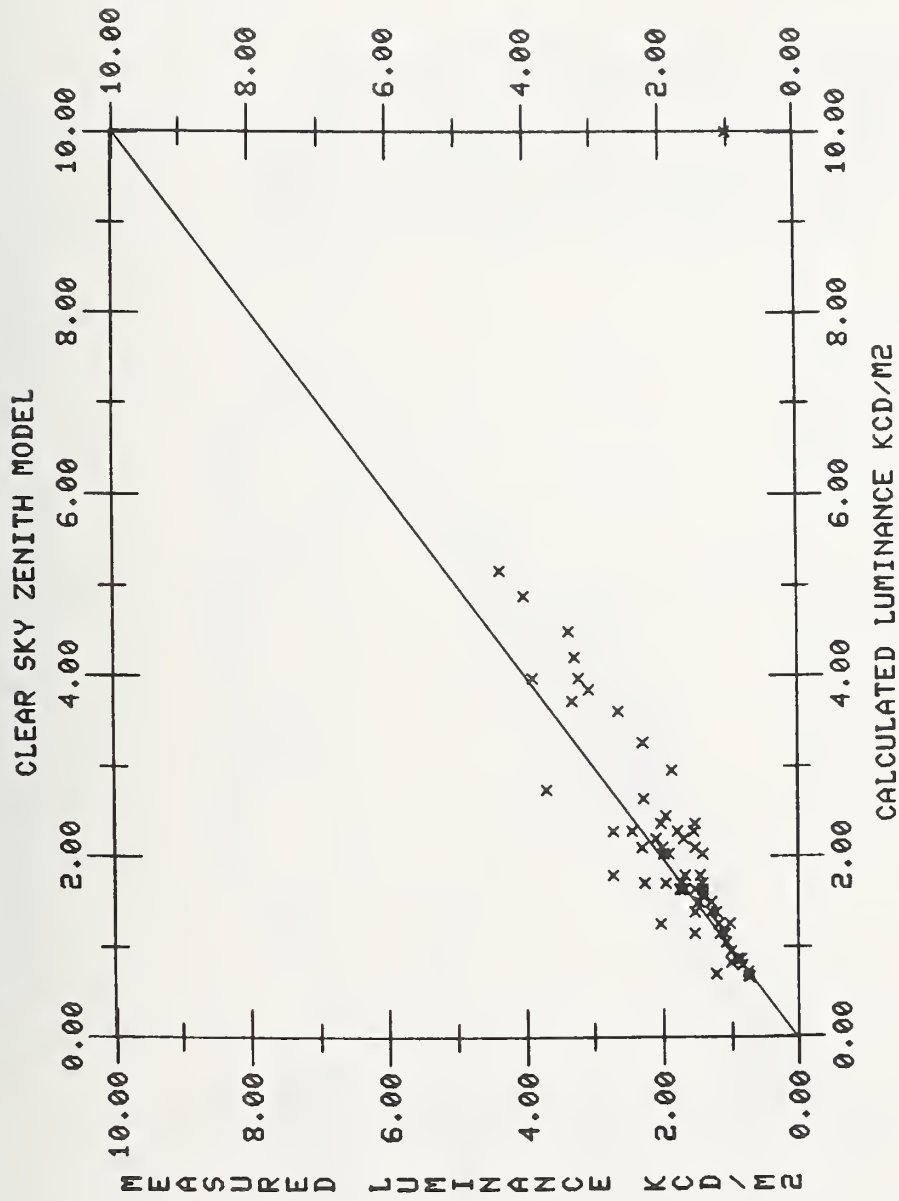


Figure 6.3 Measured zenith sky luminance verses calculated luminance using the clear sky zenith model

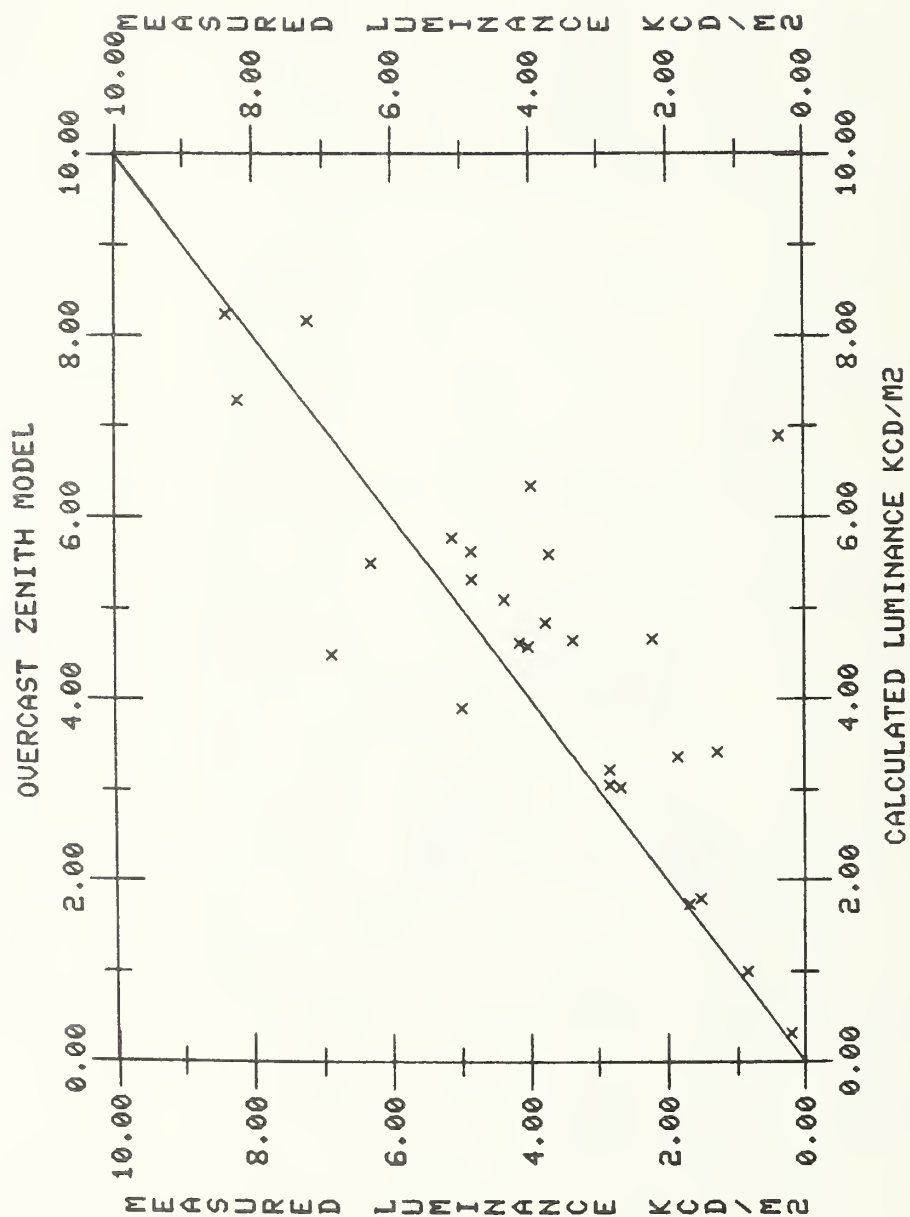


Figure 6.4 Measured zenith sky luminance verses calculated luminance using the overcast sky zenith model

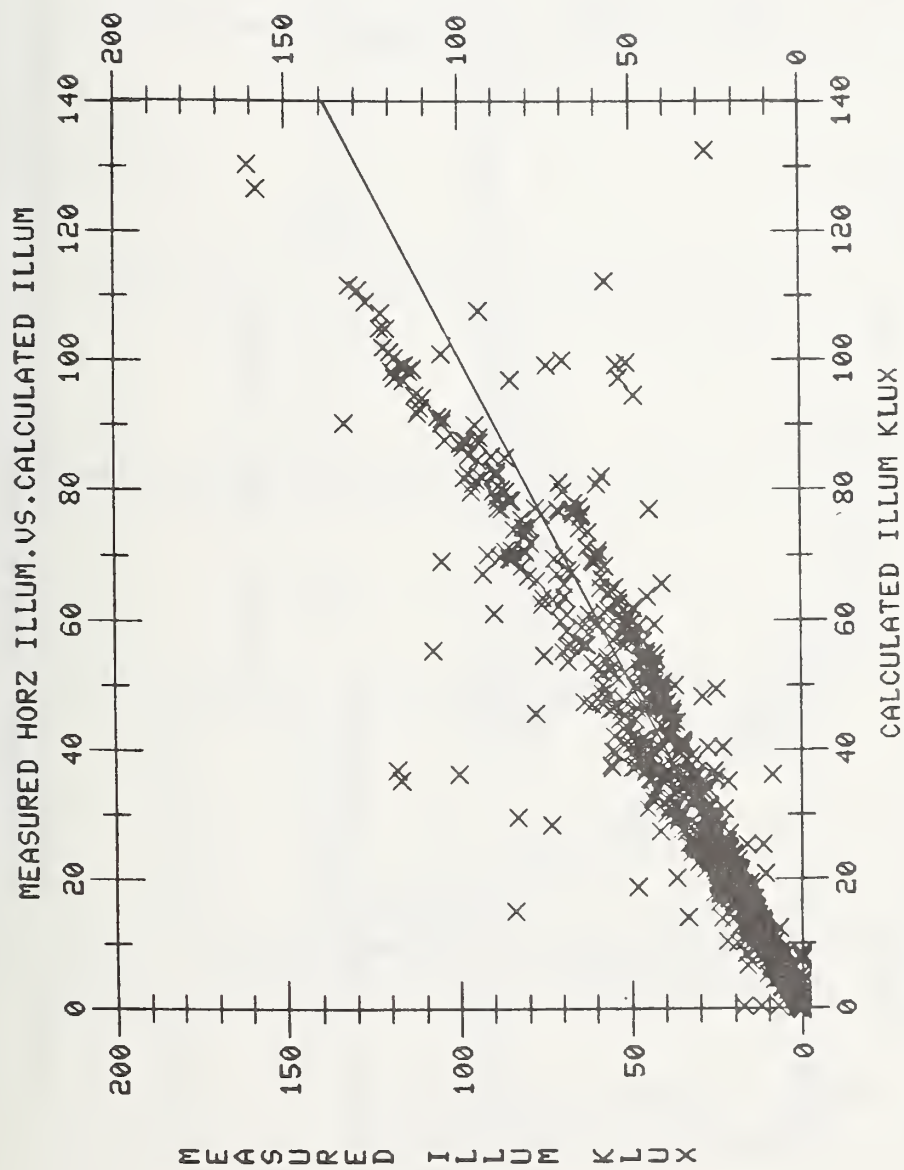


Figure 6.5 Measured horizontal illuminance verses calculated illuminance using the sky illuminance model for all sky types

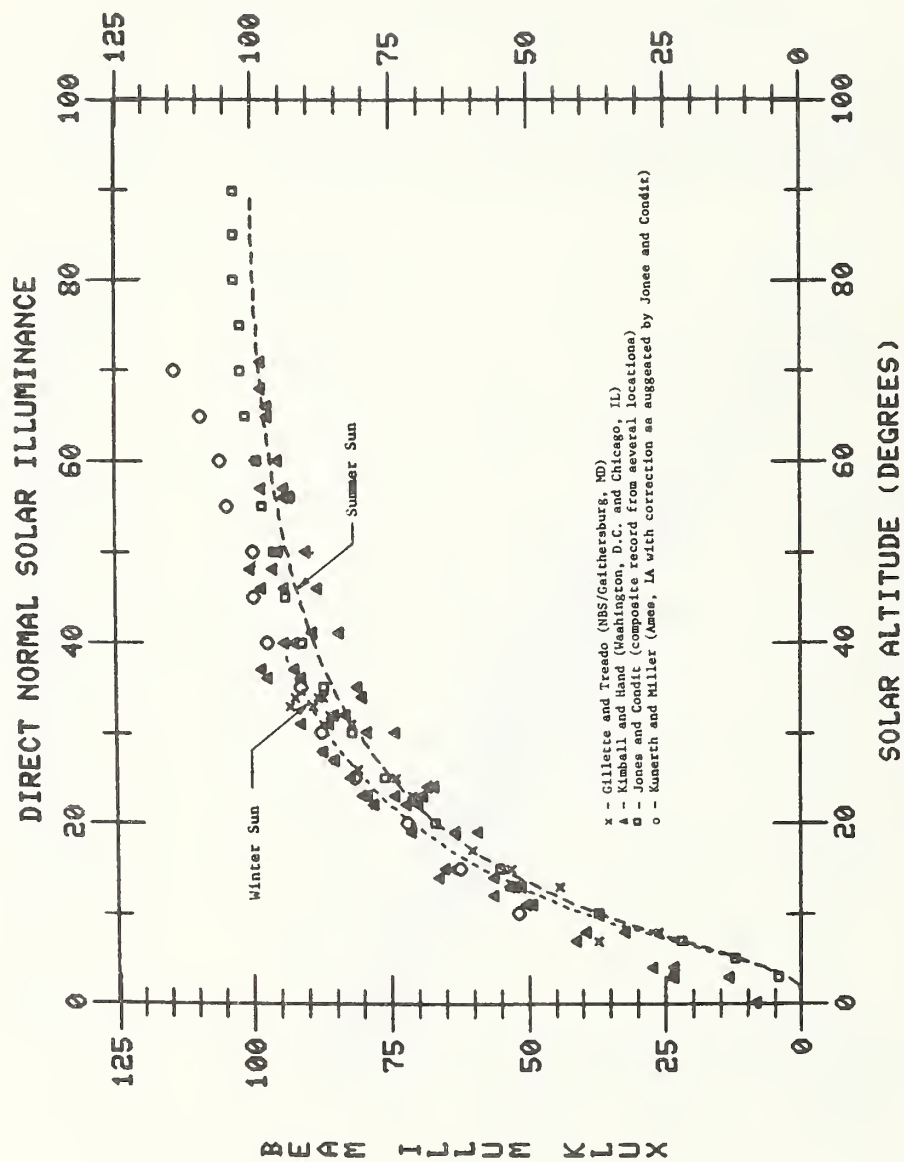
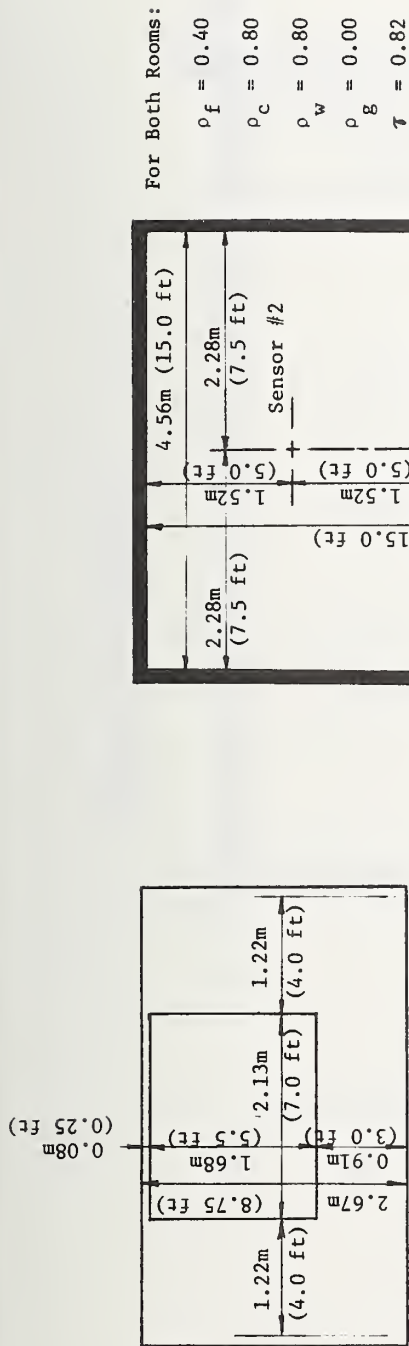


Figure 6.6 Comparison of measured sunlight illuminance with predicted illuminance of direct sunlight



Test Room No. 1

Model Scale: 1.0 inch = 1.0 ft

Test Room No. 2

Figure 6.7 Description of scale model test rooms

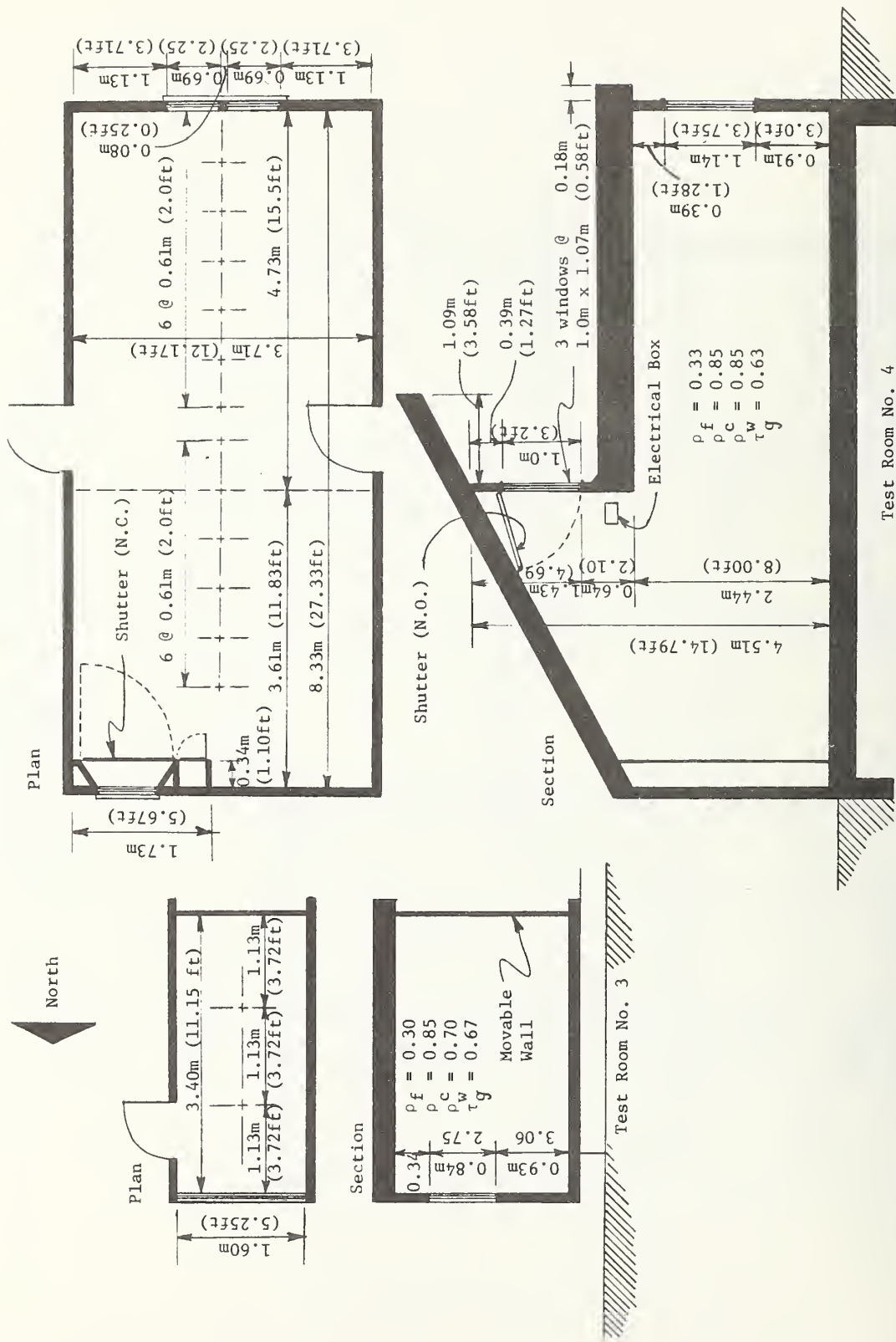


Figure 6.8 Description of full scale test rooms

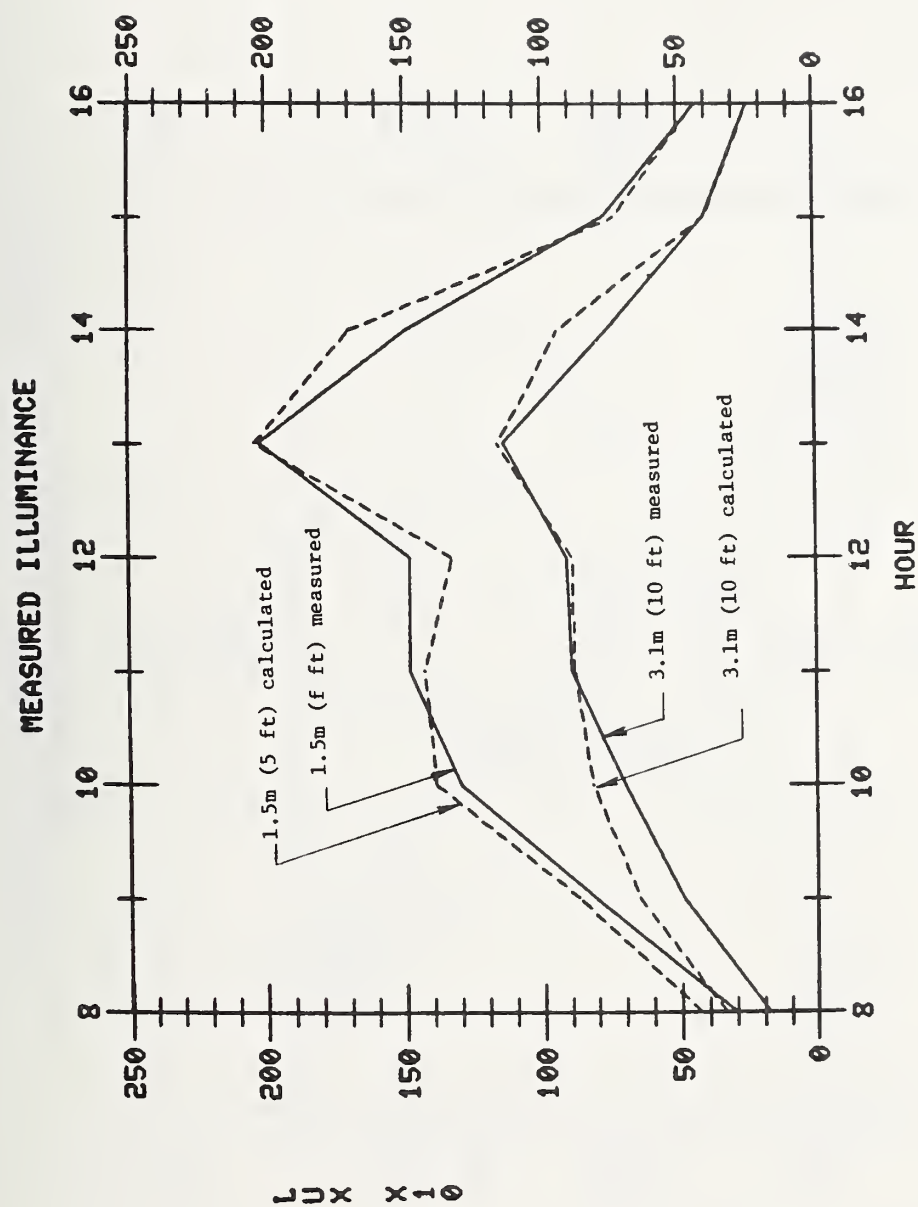


Figure 6.9 Hourly interior daylight illumination for an overcast day in room no. 1 (north fenestration)

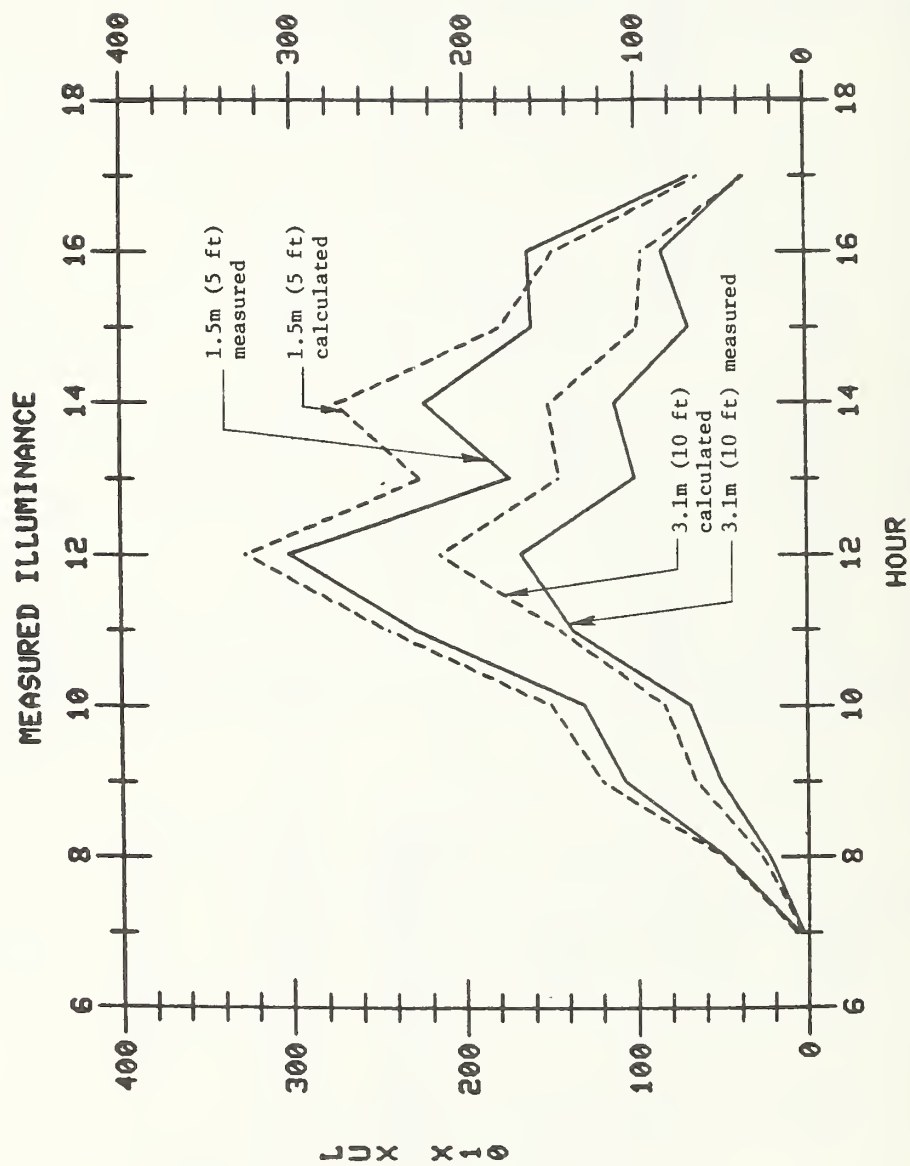


Figure 6.10 Hourly interior daylight illumination for a partly cloudy day in room no. 1 (north fenestration)

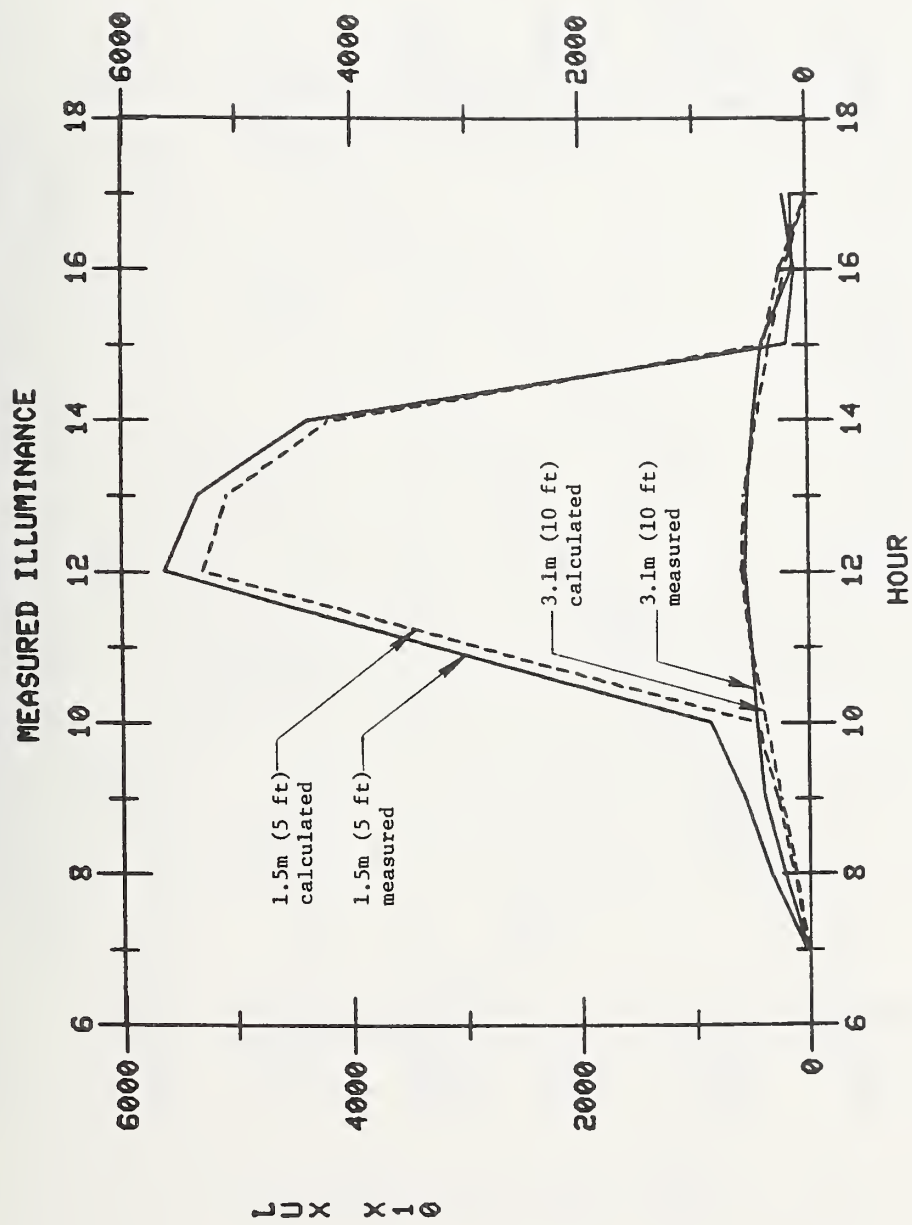


Figure 6.11 Hourly interior daylight illumination for a clear day in room no. 2 (north fenestration)

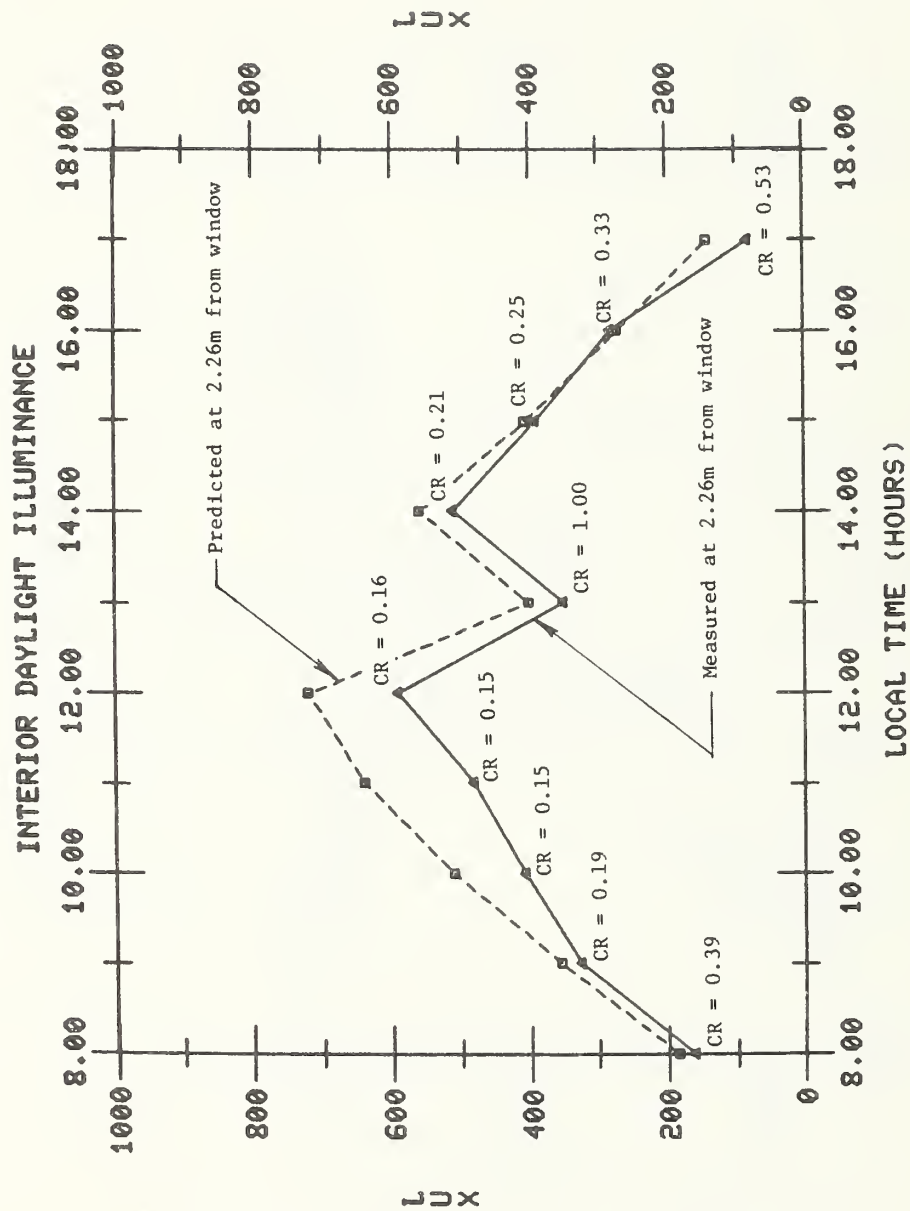


Figure 6.12 Hourly interior daylight illumination for several sky conditions in room no. 3 (north fenestration)

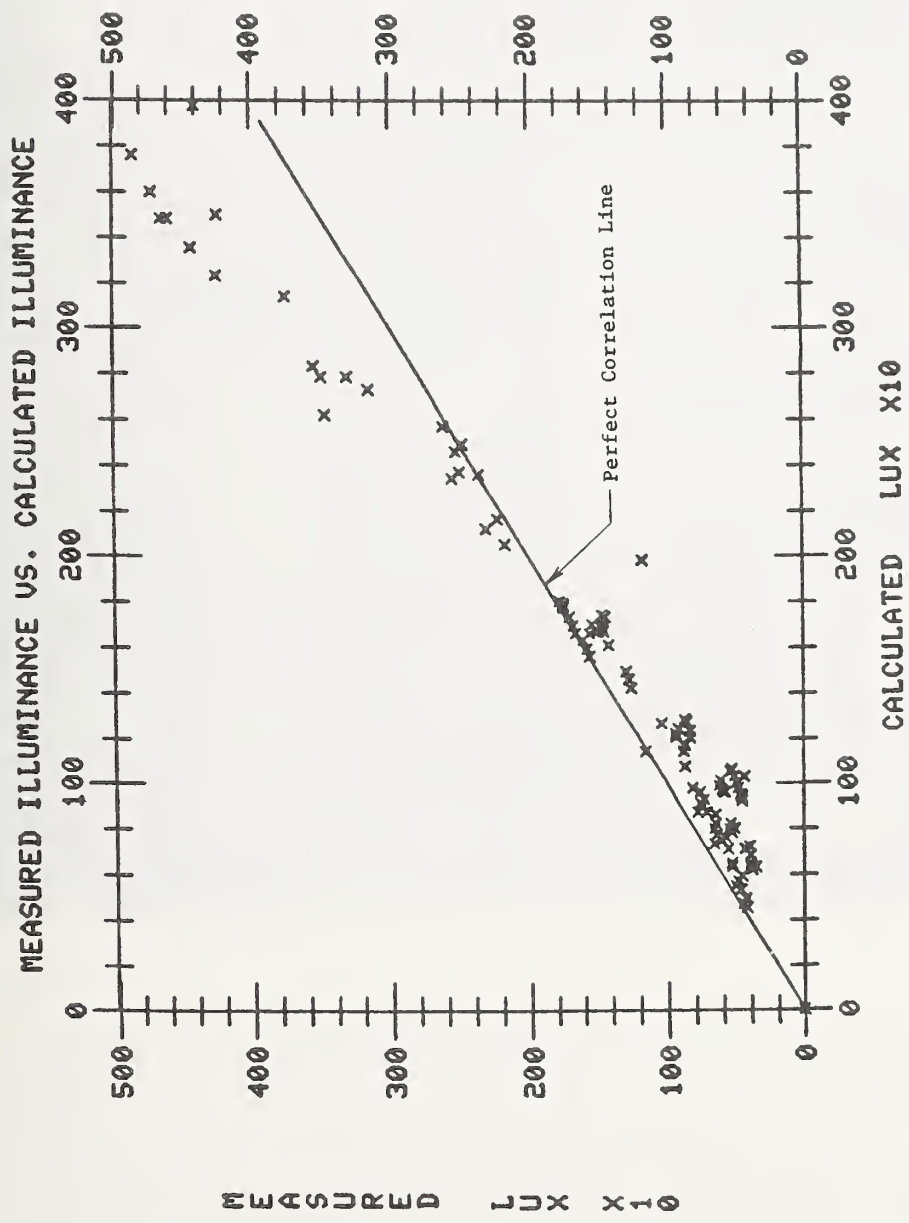
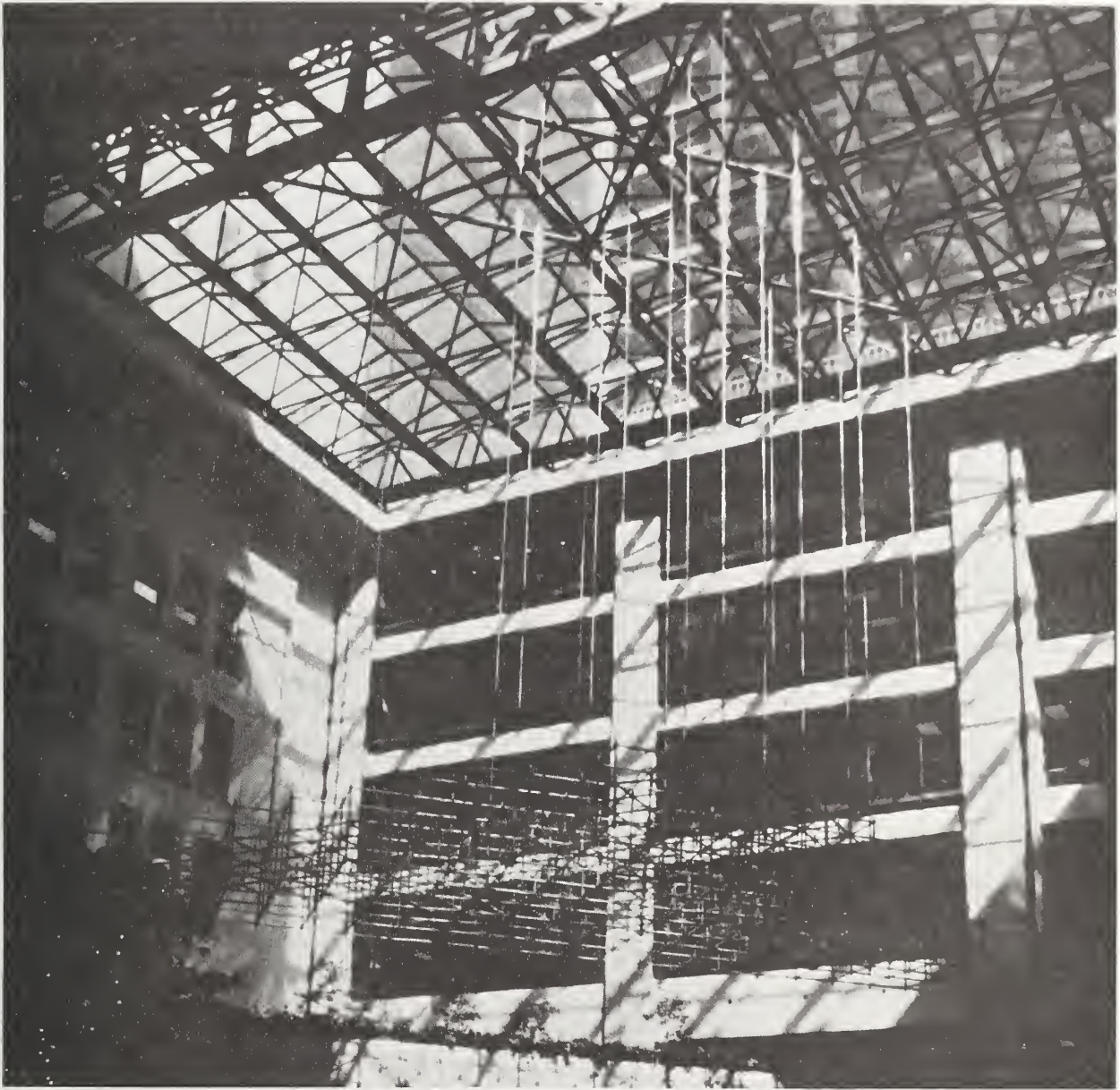


Figure 6.13 Collective plot of measured versus calculated interior illumination in room no. 4 (for south facing windows only)

*Facing page: Sunlight penetration from an
atrium in an office complex.*



7. CONCLUSIONS

A small computer model has been developed for inclusion into larger building energy simulation programs for studying the hourly energy impact of daylighting in buildings. The model is computationally fast in computer time, yet can accommodate a variety of fenestration designs and electric light dimming strategies. The model uses solar radiation and sun position data for estimating outdoor daylighting conditions, and these data are currently available in the existing hourly energy simulation programs. Although the model is streamlined for its particular application, it still simulates field conditions reasonably well, usually well within 30 percent including uncertainties in both the sky and room prediction models. It should easily fit into most building energy

programs written in Fortran 77. With its modular structure, revisions and expansions to the original model can be accomplished easily. Its modular design also lends itself to micro and mini-computer applications either as part of a small-scale energy simulation model, or as a stand alone daylighting program.

Other strengths of the DALITE model include the streamlined simulation of skylights, sloping clerestores, and vertical windows, and the capability to simulate a full range of sky conditions. Validation efforts have shown the program to perform well when compared against actual daylighting measurements under real sky conditions for a variety of room and sky scenarios.

The limits of the DALITE model include the restriction to rectangular room geometries and simplified fenestration appendages such as overhangs and side fins. While exterior louvers can be modeled as multiple minute overhangs, this technique is not always best. Further research work is therefore suggested in modeling exterior appendages, particularly with respect to specular reflections.

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APPENDIX A: DETERMINING EFFECTIVE SKYLIGHT TRANSMITTANCE

To obtain a realistic estimate of the daylighting performance of a skylight, it is necessary to provide an appropriate value for the effective (net) skylight transmittance. This effective transmittance is a composite correction for doming effects, well losses, mullion factors and sun control devices. While only an abbreviated discussion is provided here, further reference is made to the Reference Volume of the IES Lighting Handbook.[28]

The effective direct transmittance τ_D and diffuse transmittance τ_d of a horizontal skylight can both be expressed as,

$$\tau_C = \tau \times \eta_w \times \tau_m \times \tau_c \quad (A.1)$$

where,

- τ_C = the effective transmittance
- τ = the combined glazing transmittance
- η_w = the well efficiency
- τ_m = the mullion correction factor
- τ_c = the correction factor for louvers or other solar control.

The combined transmittance of a double domed (two layer) skylight is found by,

$$\tau = \frac{\tau_o \tau_i}{1 - \rho_{bo} \rho_{ti}} \quad (A.2)$$

where,

- τ_o = the transmittance of the outer dome
- τ_i = the transmittance of the inner dome
- ρ_{bo} = the reflectance of the bottom side of the outer dome
- ρ_{ti} = the reflectance of the top side of the inner dome.

To represent the effects of doming the skylight, which causes the thickness of the skylight to vary across the domed surface, a third equation can be used.[28]

$$\tau_{dome} = 1.25 \tau_{FS} (1.18 - 0.416 \tau_{FS}) \quad (A.3)$$

where

- τ_{dome} = the integrated glazing transmittance for the domed surface
- τ_{FS} = the flat sheet transmittance of acrylic (as normally given by the manufacturer).

The well efficiency is obtained by figure A.1. The well index used in the figure can be found by the equation,

$$WI = \frac{h (w + 1)}{2 w l} \quad (A.4)$$

where,

h = the well height

w = the well width

l = the well length

By computing the appropriate factors and solving equation A.1, the effective transmittances for diffuse and direct light can be provided for input into the skylight algorithm.

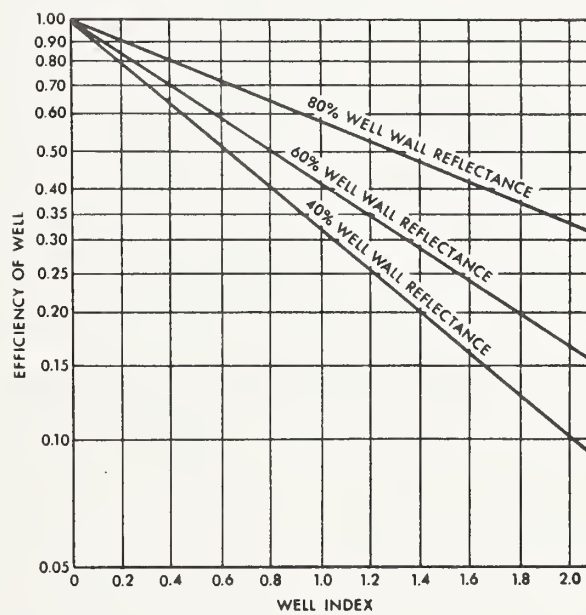


Figure A.1 Well efficiency η_w as a function of a well index and well reflectance

(from the 1981 Reference Volume of the I.E.S. Lighting Handbook, p. 9-86, used with permission)

APPENDIX B: DESCRIPTION OF VARIABLES

The following is a listing of all the important variables used within the DALITE program, including both I/O variables "seen" by the user and variables used internally. It should be noted that although it is possible to adapt the program for use in computer models that use SI units, the I/O is here given in English units for compatibility in most of the existing energy programs currently available. A conversion table to SI unit is given on page vi.

A	= total surface area of interior room surfaces (square feet)
AZM	= azimuth angle of the building off the cardinal axis, clockwise from north (degrees)
AZS	= difference in azimuth angle between the surface perpendicular and the azimuth of the sun (degrees)
ANG	= solar profile angle from horizon (radians)
ANGL1	= azimuth angle sensor makes with right edge of window (degrees)
ANGL2	= azimuth angle sensor makes with left edge of window (degrees)
ANGL3	= ANGL1 referenced to true north (degrees)
ANGL4	= ANGL2 referenced to true north (degrees)
AW	= distance from ceiling to top of window (feet)
BCF	= Basic Configuration Factor - general sloping case
BCFS	= Basic Configuration Factor - parallel surface (skylight) case
BCFW	= Basic Configuration Factor - perpendicular window case
BETA	= atmospheric turbidity coefficient (β)
CC	= length of sloped clerestory ceiling (feet)
CHI(χ)	= constant offset dimmer control coefficient (default is 0.30)
CR	= cloud ratio; ration of diffuse to total horizontal solar radiation.
CRL	= ceiling reflected light coefficient.
CNFLX	= ceiling flux coefficient; for reflected light off clerestory
DAYLT	= daylight illuminance array for "n" number of sensors (footcandles)
DAYLTE	= daylight illuminance of sensor under consideration (footcandles)

DILL = maintained design illuminance at the photocell (footcandles)

DIM = dimmer type:

- 1 - on/off switch or relay
- 2 - two level step-down; half off at half load, full off at full load.
- 3 - continuous dimming
- 4 - continuous dimming with shut-off

DP = depth of photocell from fenestration; for skylights & clerestories, distance from bottom of fenestration to workplane (feet)

DS1 = horizontal depth of sun's projection within room due to upper edge of window - see figure B2 (feet)

DS2 = horizontal depth of sun's projection within room due to lower edge of window - see figure B2 (feet)

DW = depth of skylight well (feet)

DX = distance of external obstructing building from fenestration surface (feet)

EX = extraterrestrial illuminance of the sun (footcandles)

FLUX1 = first reflected flux coefficient for surface containing the fenestration

FLUX2 = first reflected flux coefficient for left surface with respect to fenestration

FLUX3 = first reflected flux coefficient for surface opposite fenestration

FLUX4 = first reflected coefficient for right surface with respect to fenestration

FLUX5 = first reflected flux coefficient for the ceiling

FP = fin projection from the fenestration (feet), two fins are assumed on either side of fenestration

GAMMA = angular great circle distance between the sun and the specified point in the sky (radians)

GRDLIT = exterior horizontal illuminance incident on the ground (footcandles)

GRL = ground reflected coefficient

H = height of fenestration (feet)

H1 = height distance from fenestration to bottom of wall surface (feet)

H2 = height distance as shown in figure B.3 (feet)
 H3 = height distance as shown in figure B.3 (feet)
 H4 = height distance as shown in figure B.3 (feet)
 H5 = height distance as shown in figure B.3 (feet)
 HH = height distance as shown in figure B.3 (feet)
 HH1 = height distance as shown in figure B.3 (feet)
 HH2 = height distance as shown in figure B.3 (feet)
 HH3 = height distance as shown in figure B.3 (feet)
 HH4 = height distance as shown in figure B.3 (feet)
 HH5 = height distance as shown in figure B.3 (feet)
 HX = height of external obstruction above the workplane (feet)
 HC = height of clerestory projection above ceiling plane (feet)
 HC is negative if clerestory is sloped, positive if roof monitor ($\phi=0$)
 HHC = the distance from the top of the clerestory fenestration to the
 clerestory ceiling (feet)
 JUL = Julian date from 1 (January 1) to 365 (December 1)
 L = length of skylight (feet)
 L1 = length distance from room reference to skylight reference (feet)
 L2 = length distance as shown in figure B.4 (feet)
 L3 = length distance as shown in figure B.4 (feet)
 LC = distance from room reference to clerestory reference in length
 direction (feet)
 LLOAD = incremental instantaneous lighting load due to single phototcell and
 single aperature (kilowatts)
 LLOADN = the instantaneous lighting load associated with photocell "n"
 (kilowatts)
 LLOADX = the hourly sum of all photo-controlled lighting loads per room
 (kilowatts)

LOAD = full connected lighting load associated with each photocell, including ballast losses (kilowatts)

LS1 = length distance from room reference to near edge of sunlight patch from skylight on workplane (feet)

LS2 = length distance from room reference to far edge of sunlight patch from skylight on workplane (feet)

M = mullion correction factor; the fractional loss in transmittance due to mullions and glazing bars

NA = number of aperatures within room

NL = number of luminare switch/dimmers within room

OMEGA = atmospheric water vapor content in centimeters of water (ω)

OP = horizontal overhang projection from the fenestration (feet)

PHASE = percentage of clear sky luminance and sun illuminance available

PHI = in the SUNN subroutine the vertical profile angle of the sun-see figure B.2 (radians); in the DL subroutine the slope of the clerestory from the horizontal (radians)

PL = position of photocell along the length direction from the room reference (feet)

PSI = complement angle of PHI; the slope of the clerestory from the zenith (radians)

PSL = percentage of supplemental light necessary (decimal)

PW = position of photocell along the width direction from the room reference (feet)

RAVE = average reflectance of all interior room services (decimal)

RCN = reflectance of the ceiling (decimal)

RFL = reflectance of the floor (decimal)

RG = reflectance of the ground immediately outside the fenestration (decimal)

RL = apparent room length as seen by the particular fenestration (feet)

RHM = room height (feet)

RML = interior room size in length direction (feet)

RMN = room number (just an identifier)
 RMW = interior room size in width direction (feet)
 RRF = roof reflectance immediately outside clerestory (decimal)
 RRL = roof reflected light coefficient
 RW = apparent room width as seen by the particular fenestration (feet)
 RWL = reflectance of the interior wall surfaces (decimal)
 RX = average reflectance of external obstruction (decimal)
 SIDLIT = total exterior vertical illuminance on window surface (footcandles)
 SKYLIT = sky illuminance at fenestration centroid (footlamberts)
 SN = surface number of fenestration:
 1 - if north facing 6 - if clerestory north facing
 2 - if east facing 7 - if clerestory east facing
 3 - if south facing 8 - if clerestory south facing
 4 - if west facing 9 - if clerestory west facing
 5 - if ceiling/roof
 SNL = sunlight coefficient
 SRD = diffuse horizontal solar radiation (Btu/S.F-hr.)
 SRT = total horizontal solar radiation (Btu/S.F-hr.)
 SUMFLX = sum of the interior surface flux coefficients
 SUNALT = solar altitude above horizon (degrees)
 SUNAZ = solar azimuth clockwise from north (degrees)
 SUNBM = solar beam illuminance direct normal (footcandles)
 SUNFLX = sun flux coefficient
 SUNLIT = the horizontal illuminance due to beam sunlight (footcandles)
 SURFAZ = azimuth angle from surface normal clockwise to true north (degrees)
 T = average visible transmittance of glazing (including a maintenance factor)
 THETA = altitude angle between the window centroid and the photocell (degrees)

TNX = angular visible transmittance, accounting for angle of incidence
 W = width of fenestration (feet)
 W1 = width distance of window or skylight from surface reference (feet)
 W2 = width distance as shown in figure B.3 (feet)
 W3 = width distance as shown in figure B.3 (feet)
 W4 = width distance as shown in figure B.3 (feet)
 W5 = width distance as shown in figure B.3 (feet)
 W6 = width distance as shown in figure B.3 (feet)
 W7 = width distance as shown in figure B.3 (feet)
 WA = window area (square feet)
 WC = width of clerestory opening (feet)
 WC1 = width distance of clerestory opening from room reference (feet)
 W1NAZ = viewing azimuth angle between photocell position (at work plane) and window/skylight centroid; clockwise from north (degrees)
 WP = width distance of photocell with respect to surface reference - see figure B.3 (feet)
 WS1 = width distance of near edge of skylight sun projection from room reference at workplane (feet)
 WS2 = width distance of far edge of skylight sun projection
 WX = depth of skylight well from ceiling to fenestration (feet)
 XDL = direct skylight coefficient
 XI(ξ) = linear dimmer control coefficient
 XIRL = internally reflected light coefficient
 XERL = externally reflected light coefficient
 ZLUM = zenith sky luminance (footlamberts)

ZLITE (42, 12)

	1	2	3	4	5	6	7	8	9	10	11	12	
1	RMH	RML	RMW	AZM	RCN	RWL	RFL	RG	RX	NA	NL	RMN]-Room]-Information]-Sky]-Information
2	SUNALT	SUNAZ	SRD	SRT	β	ω		JUL					
3	W	H	H1	W1	+T -	M	HX	DX	SN	OP	AW	FP]-For Window
4	W	L	L1	W1	+T -	M	HX	DX	SN]-For Skylight
5	W	H	H1	W1	+T -	M	WC1	LC1	SN	WC	LC	HC]-For Clerestory
6													
7													
8													
9													
10													
11													
12													
13													
14													
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18													
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24													
25													
26													
27													
28													
29													
30													
31													
32													
33	PW	PL	DILL	DIM	LOAD	ξ	X			(DAYLITE)	(LOADX)	(GRDLIT)	
34													
35													
36													
37													
38													
39													
40													
41													
42													

- For 30
Apertures

- For 10
Photocells

Figure B.1 Input/output array

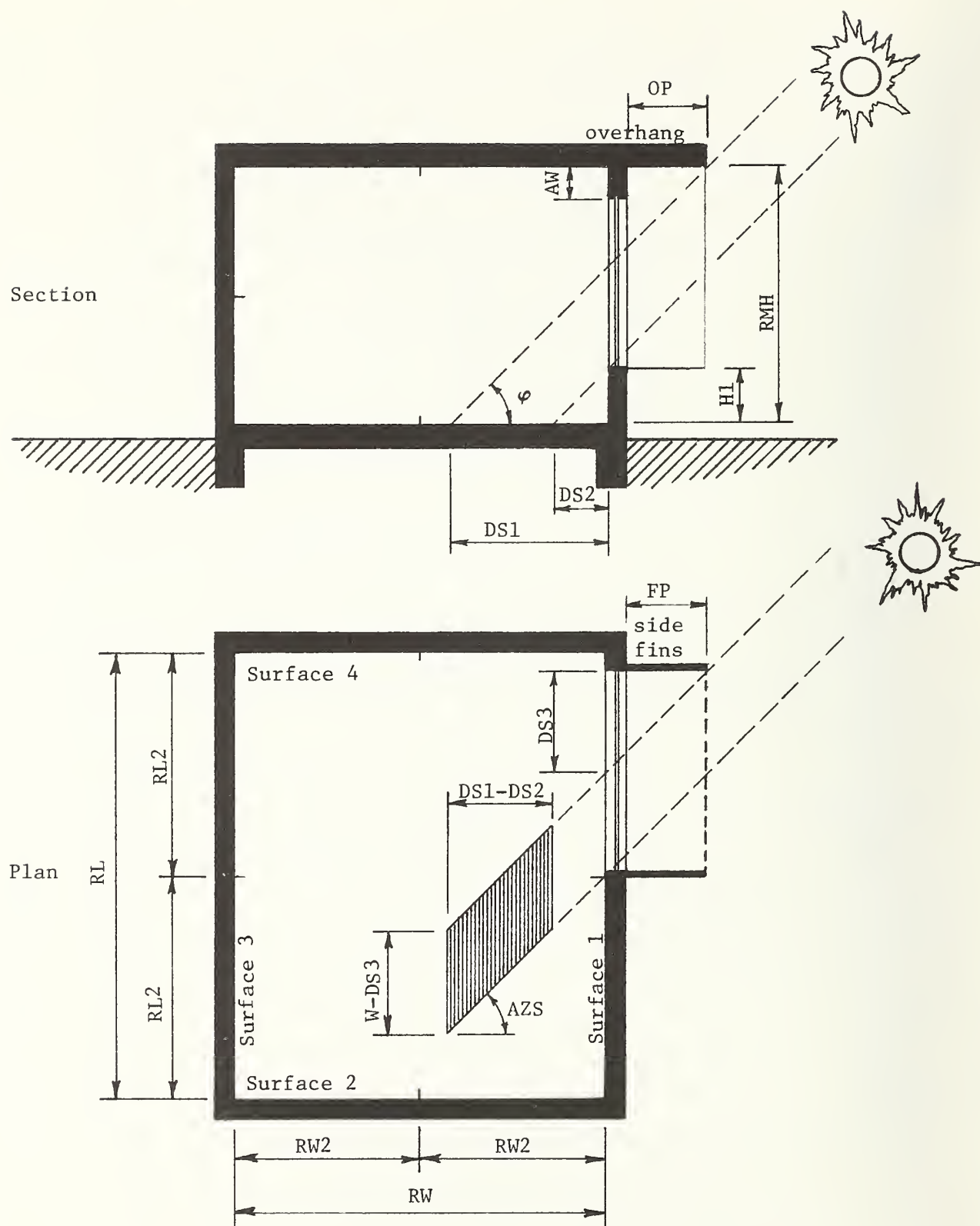


Figure B.2 Room coordinates defined with respect to glazing surface in IRL subroutine

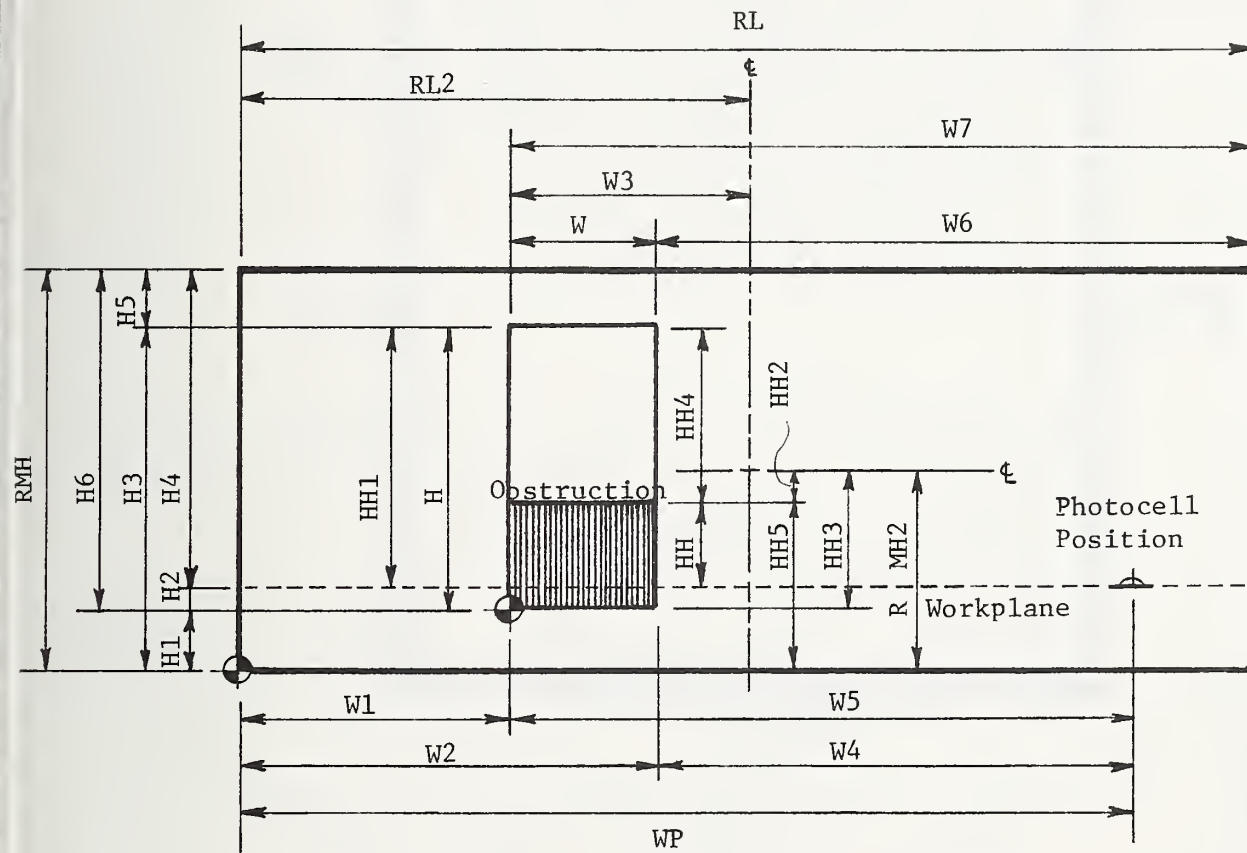


Figure B.3 Wall surface dimensions used internally in the DALITE program

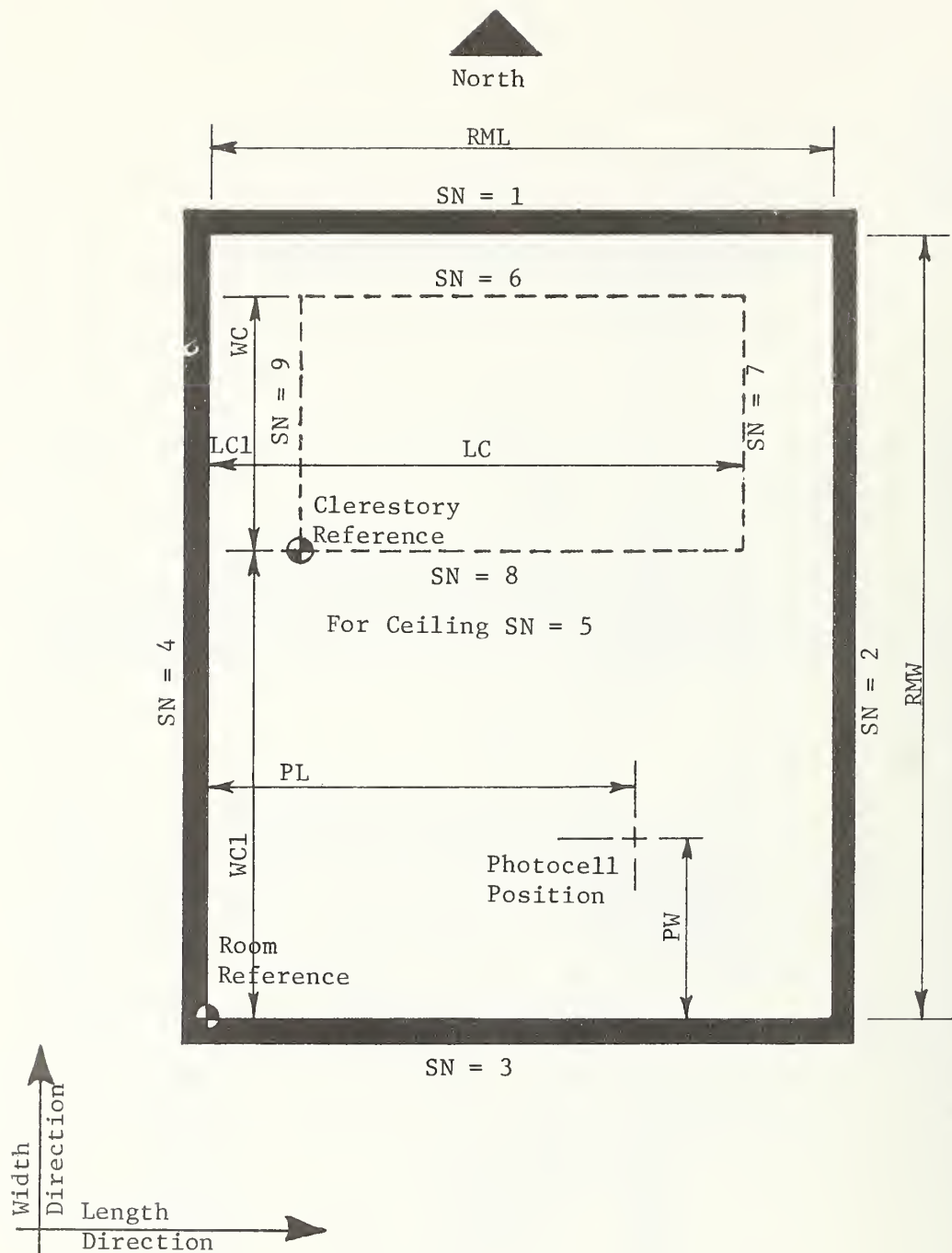
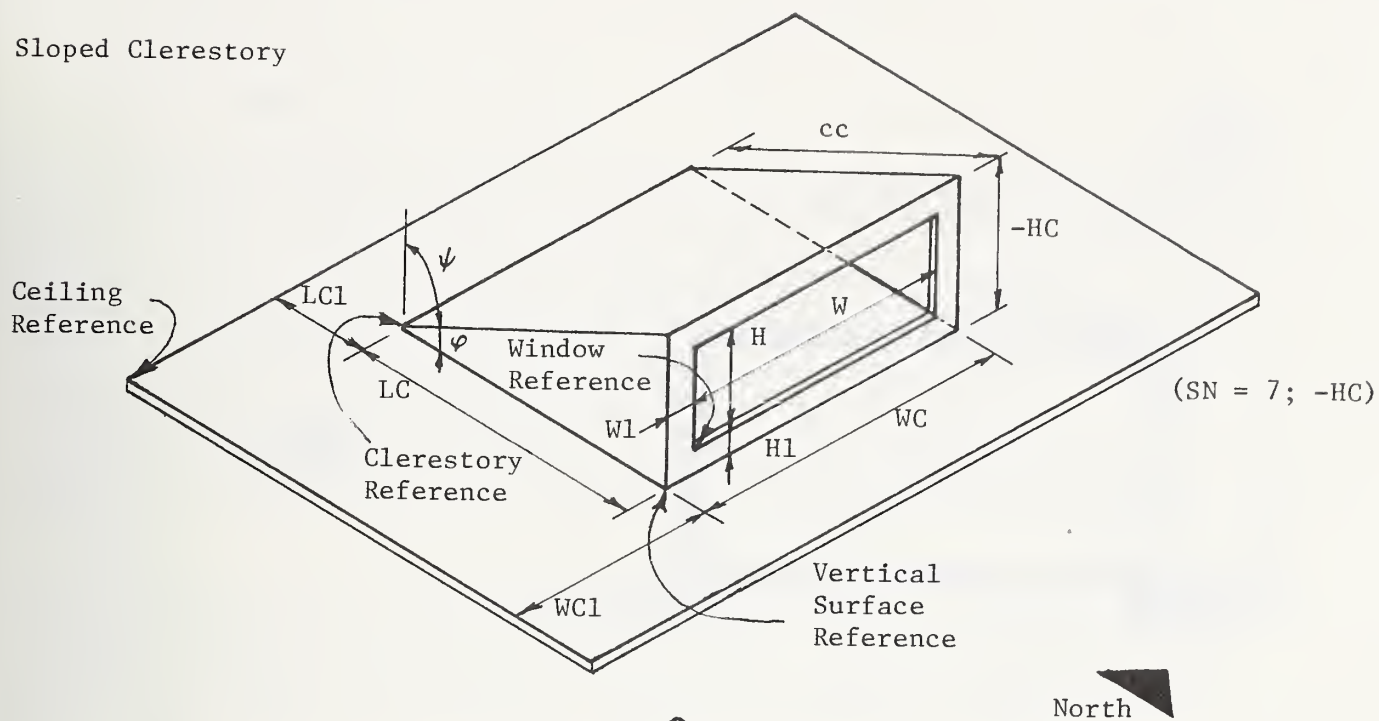


Figure B.4 Surface numbering sequence and clerestory reference variables

Sloped Clerestory



Rectangular Clerestory (Roof Monitor)

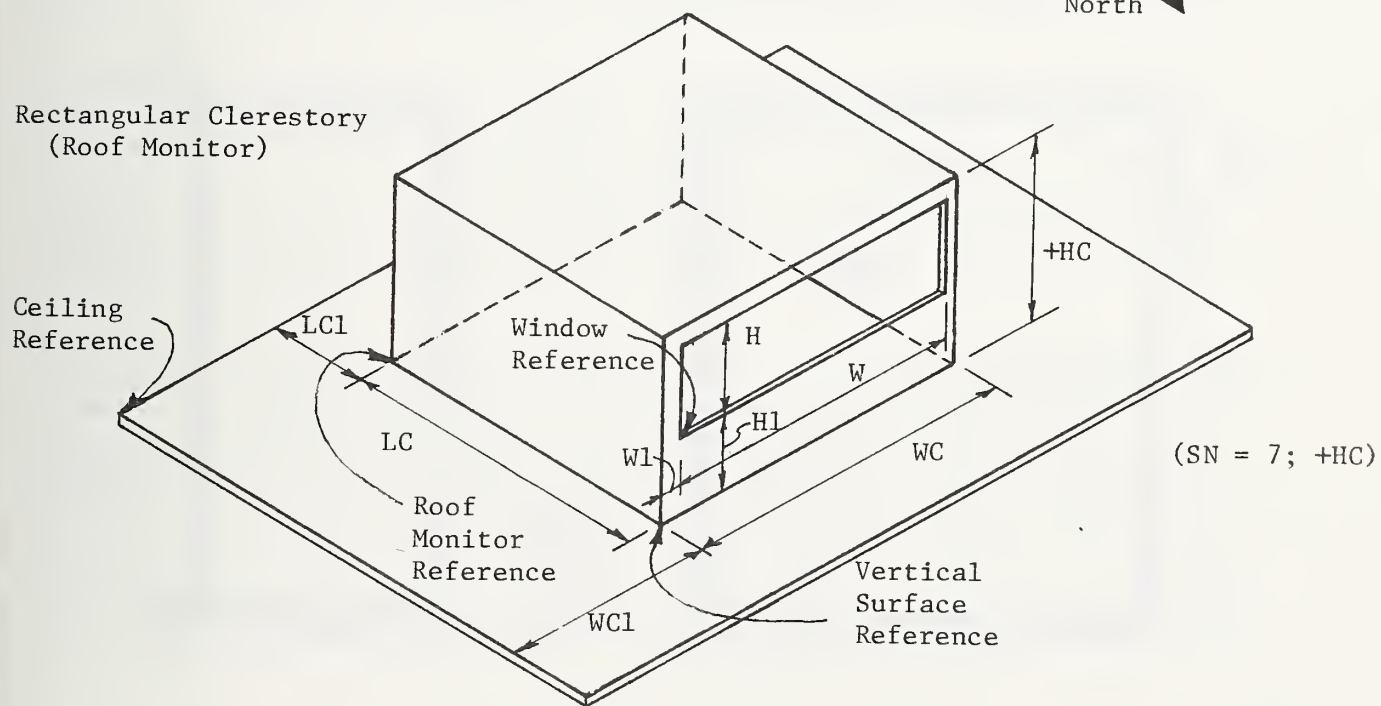


Figure B.5 Clerestory coordinates

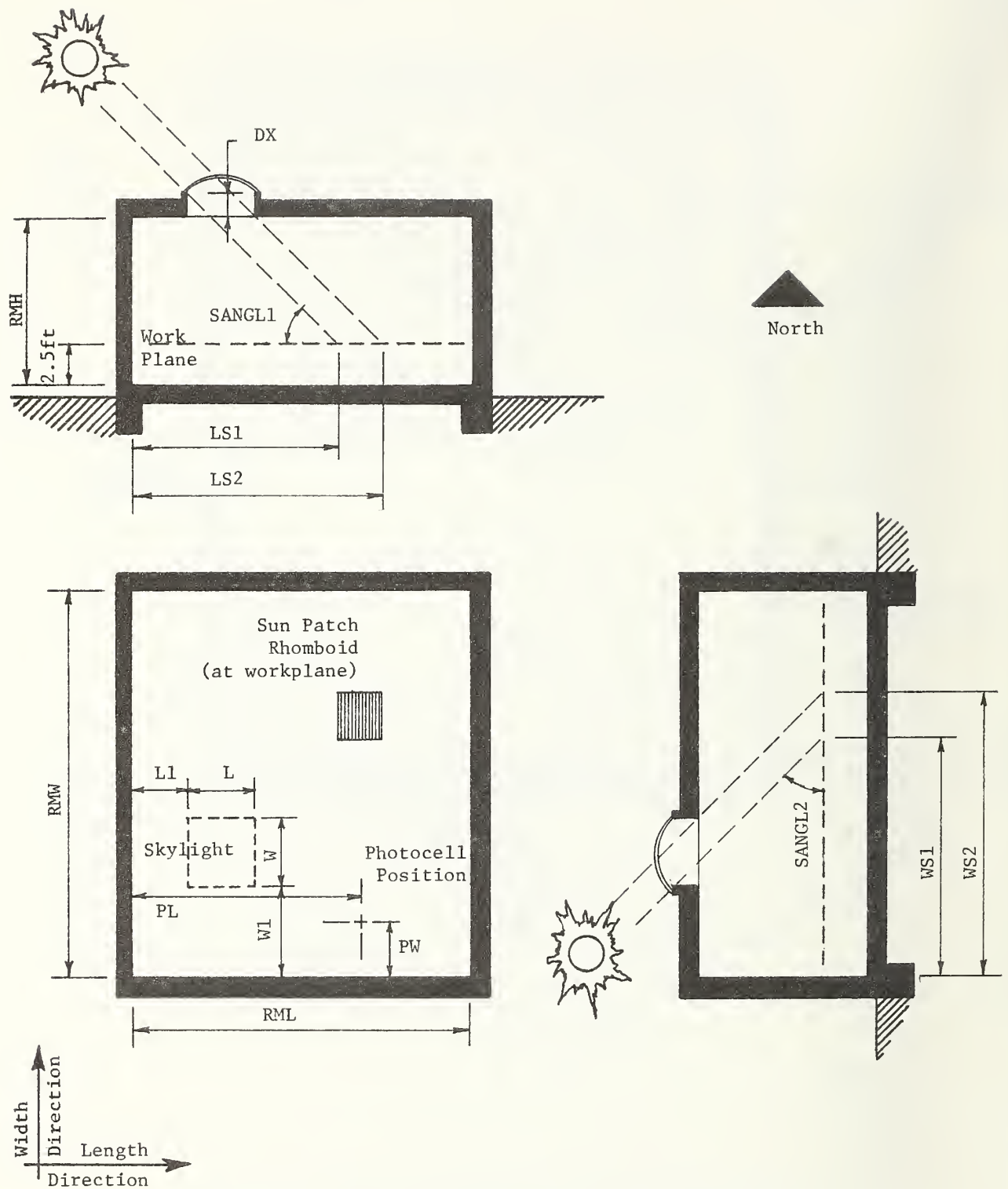


Figure B.6 Sun projection variables for skylights

APPENDIX C: SUBROUTINE INTERFACING

Interfacing the DALITE subroutines with an existing FORTRAN program is accomplished by changes at two locations in the main program. The first is at initialization. Here the common block for the two input/output arrays and the dimensioning of the other internal arrays are assigned (figure C.1). Here also READ statements are given, following the array declarations, where the building and component characteristics are defined for the daylighting I/O array along with the other building characteristic assignments. Such READ statements may be provided either through a pre-processor or through various statements within the main program. At this point the room, aperture, and photocell information is assigned within the ZLITE array (see figure B.1) where it will be called later by the various daylighting subroutines during execution.

The second revision is done inside the hourly (or other time step) loop. Here input assignments are given for each hourly set of sky conditions preceeding the CALL statement for the daylighting analysis. Daylighting output information is then passed from the DALITE subroutine to the main program via the ZLITE array, where it is used as a part of the hourly load compilation.

The adjusted electric load (WLAMP) and the exterior horizontal illuminance (FCDAY) are the normal output values. However, illuminance at each sensor position is also accessible from the array DAYLT (n), n being the sensor number. Further output information, such as wall luminances, luminance ratios, and the like can also be obtained, but program revisions would be necessary; normally such data would be too exhaustive to include in an energy simulation, and was therefore not specified as part of the normal output.

Since the daylighting interreflection routine is room-specific and models a rectangular room geometry, a few revisions may be necessary for programs that do not prescribe set room dimensions or for cases where the assumption of a rectangular room is invalid. Two options are possible. The first is to approximate an equivalent (or effective) room height, width, and depth for the enclosed volume. The second option is to leave out the room geometry and surface reflections altogether, which would avoid the calculation of any inter-reflected light. This latter option is a good one when there is substantial uncertainty in the room configuration; this option is conservative, yet not excessively so since interreflected light is normally a small fraction of the total.

C-2

Variable Name	Variable* Specification	Variable Limits
RMH	REAL	None
RML	REAL	None
AZM	REAL	Minimum = 0.; Maximum = 360.
RCN	REAL	Must be decimal fraction less than 1.00
RWL	REAL	Must be decimal fraction less than 1.00
RFL	REAL	Must be decimal fraction less than 1.00
RG	REAL	Must be decimal fraction less than 1.00
RX	REAL	Must be decimal fraction less than 1.00
NA	REAL (Assigned)	Limit is number used in NNN parameter statement
NL	REAL (Assigned)	Limit is number used in LLL parameter statement
RMN	REAL	NONE
SUNALT	REAL	IF SUNALT \leq 5., SUNLIGHT = 0.
SUNAZ	REAL	NONE
SRD	REAL	SRD must be \leq SRT
SRT	REAL	NONE
BETA(β)	REAL	Allowable values for β are 0.05, 0.10, & 0.20
OMEGA(ω)	REAL	Allowable values for ω are 1.0, 2.0, 3.0, 4.0, & 5.0
JUL	REAL (Assigned)	Minimum = 0.; Maximum = 365.

* Format is arbitrary and depends only on the format specified in the READ statement of the main program.

Figure C.2 Input variable specifications for room and sky data

Variable Name	Variable* Specification	Variable Limits
W	REAL	None
H	REAL	None
L	REAL (Assigned)	None
H1	REAL	None
L1	REAL (Assigned)	None
W1	REAL	None
T	REAL	Must be decimal fraction less than 1.00
M	REAL	Must be decimal fraction less than 1.00
HX	REAL	None
WC1	REAL	None
DX	REAL	None
SN	REAL	Minimum = 1.; Maximum = 9.
OP	REAL	NONE
WC	REAL	Must be > W + W1
AW	REAL	NONE
LC	REAL (Assigned)	NONE
FP	REAL	NONE
HC	REAL	Must be > H + H1
PW	REAL	If PW = 0., DAYLIGHT contribution is assumed zero.
PL	REAL	NONE
DILL	REAL	NONE
DIM	REAL	Allowable values are 1., 2., 3., & 4.
LOAD	REAL (Assigned)	NONE
XI	REAL	Must be decimal fraction less than 1.00
CHI	REAL	Must be decimal fraction less than 1.00

* Format is arbitrary and depends only on the format specified in the READ statement of the main program.

Figure C.3 Input variable specifications for fenestration data

Variable Name	Variable* Specification	Variable Limits
DAYLTE	REAL	None
LOADX	REAL (Assigned)	None
GRDLIT	REAL	None
DAYLT(n)	REAL	None

* Format is arbitrary and depends only on the format specified in the READ and WRITE statements of the main program.

Figure C.4 Output variable specifications



APPENDIX D: SAMPLE RUN

SAMPLE RUN OF A BUILDING DAYLIGHTED WITH CLERESTORIES

Location: Washington, D.C. Latitude = $38^{\circ} 5'N$ Longitude = $77^{\circ} 0'W$
 Fenestration: Three north facing clerestories
 Lighting Control: Five banks of fluorescent luminaires at 1.25 KW each continuous dimming (50 fc minimum illuminance)

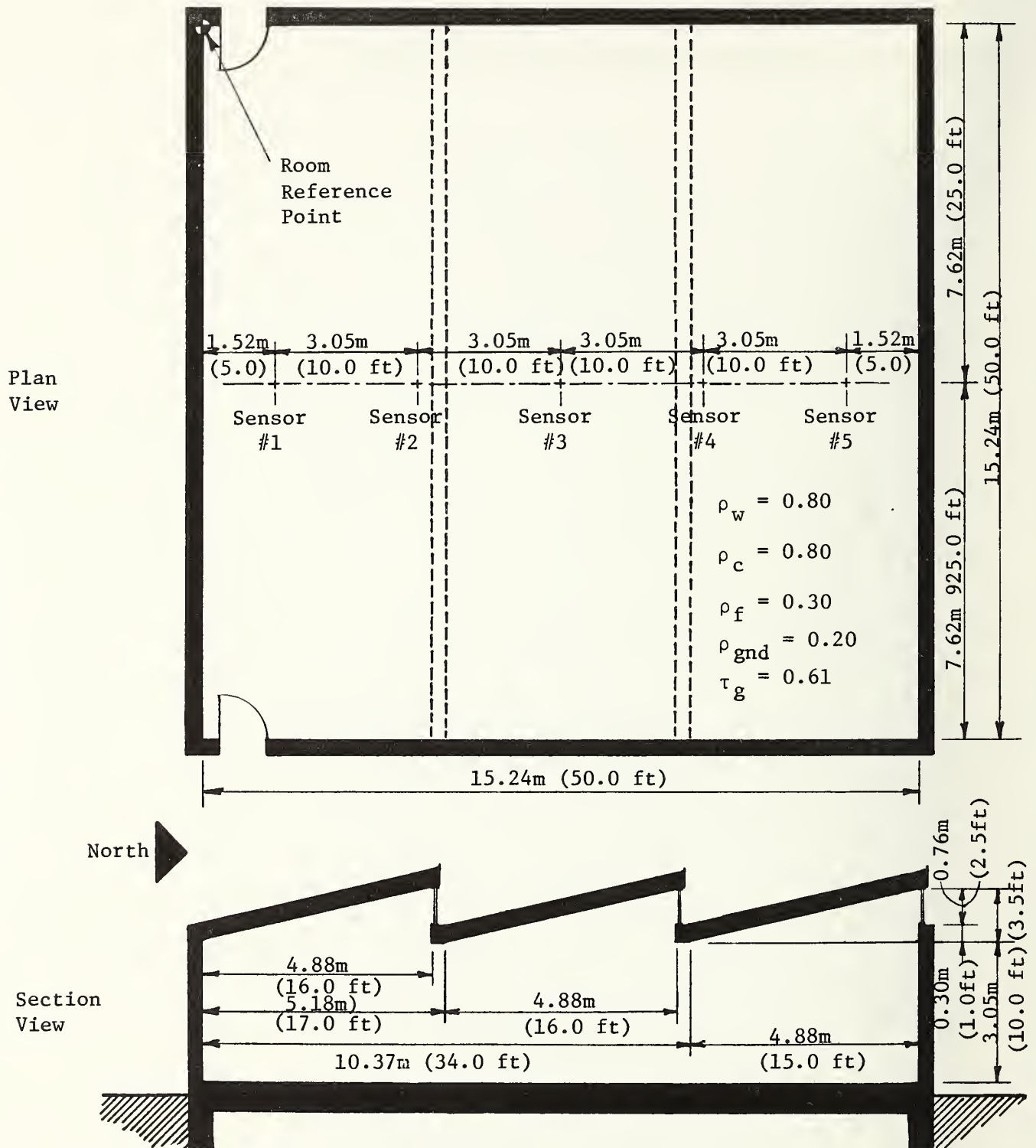


Figure D.1 Sample Building

OFFICE BUILDING W/ 25N% CLERE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
.00	.00	.00	.00	.00	.00	.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.50	.00	.00	.00	.00	.00	.00

LIGHTING SCHEDULE FOR WEEKDAYS

DATA SHEET NO 8: ROOMNO 1.00 QUALITY .25
 Room number identifier
 W/S.F. lighting load that is not affected by dimming strategy
 QLITX(NK, JJ) = The hourly schedule in percent of full load lighting power

DATA SHEET NO 11:

RCN	RWL	RFL	RG	RX	NA	NL
.80	.80	.30	.20	.00	3.00	5.00

DATA SHEET NO 12A8B:

RML	RMW	RMH
50.00	50.00	10.00

DATA SHEET NO 13B:

W	H	L1/H1	W1	T	M	HX/WC1	DX/LC1	SN	(WC)	(LC)	(HC)
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
50.00	10.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
50.00	10.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
50.00	2.50	1.00	.00	.61	1.00	.00	.00	6.00	16.00	50.00	-3.50
50.00	2.50	1.00	.00	.61	1.00	17.00	.00	6.00	16.00	50.00	-3.50
50.00	2.50	1.00	.00	.61	1.00	34.00	.00	6.00	16.00	50.00	-3.50

DATA SHEET NO 14:

PW	PL	DILL	DIM	LD	ξ	κ
5.0025	.0050	.00	4.00	1.25	.00	.00
15.0025	.0050	.00	4.00	1.25	.00	.00
25.0025	.0050	.00	4.00	1.25	.00	.00
35.0025	.0050	.00	4.00	1.25	.00	.00
45.0025	.0050	.00	4.00	1.25	.00	.00

Fenestration input data

Lighting control input data

Default values used

Full connected power load of light bank (KW)

Continuous dimming

Design illuminance (fc)

Sensor location

Figure D.2 Input from main energy simulation program

[illegible]

Figure D.3 DALITE input snapshot for a specified hour

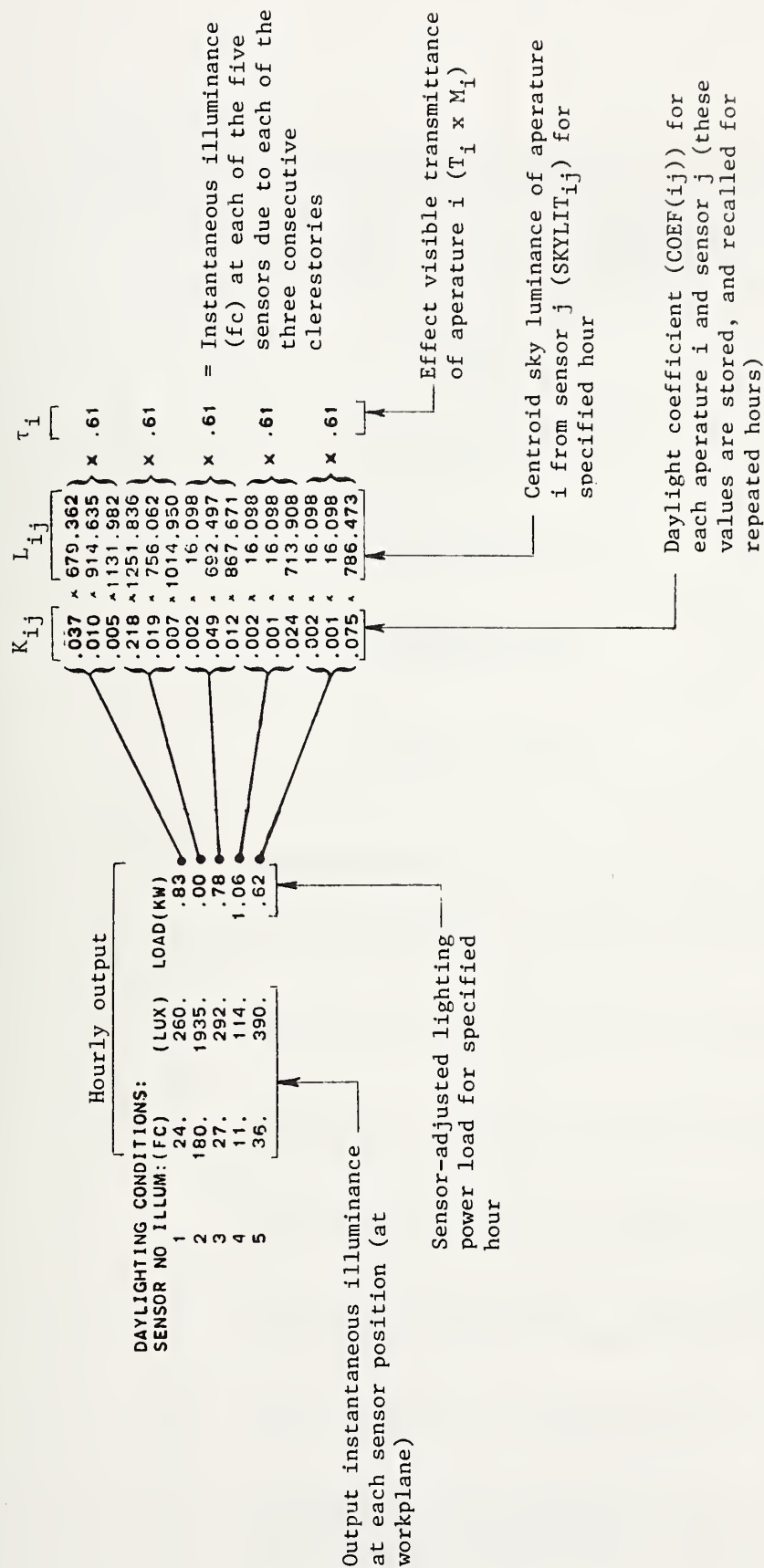


Figure D.4 DALITE output snapshot for a specified hour

APPENDIX E: PROGRAM LISTING

A FORTRAN 77 listing of the DALITE program is given on the following pages. The listing is subdivided into four sections and includes a diagrammatic representation preceding each. The code is the UNIVAC version of FORTRAN 77.

E.1 The DALITE subroutine

E.2 The SKYLUM subroutine

E.3 The RMLITE subroutine

E.4 The LLOAD subroutine

**BLOCK DIAGRAM -
PREDICTS ENERGY FROM COMPLETE SYSTEM**

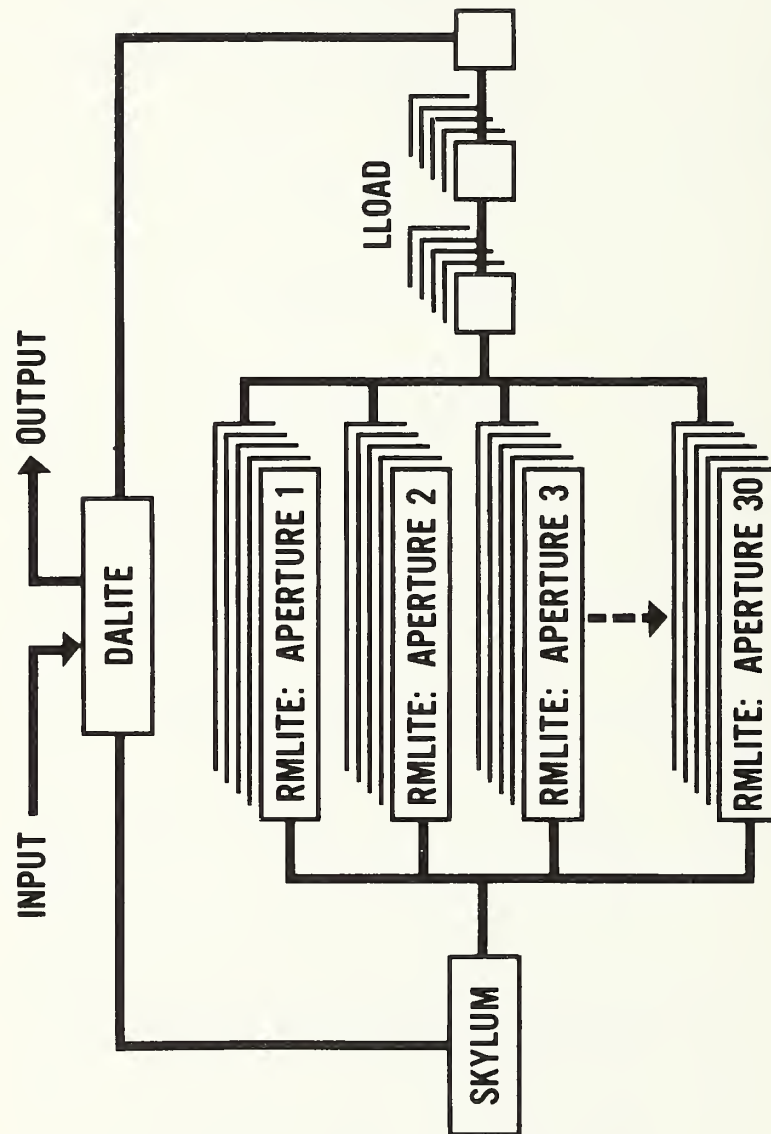


Figure E.1 Block diagram for predicting hourly daylight and its associated adjusted electric lighting energy

Q\$O\$Q\$*GARY(1).DALITE(16)

```

1      SUBROUTINE DALITE(COEF,SURFAZ,WINAZ,THETA,WP,DP,NA,NL,ITEST)
2      C
3      C      ANALYZES THE HOURLY DAYLIGHTING CONDITIONS AND
4      C      CALCULATES HOURLY ELECTRIC LIGHTING ENERGY REQUIREMENTS.
5      C      THESE DALIGHTING ALGORITHMS WERE DEVELOPED BY GARY GILLETTE.
6      C
7      C
8      C      NOTE: ALL DISTANCES ARE IN FEET AND ALL ANGLES IN DEGREES.
9      C
10     C      ROOM VARIABLES:
11     C
12     C      RMH      =ROOM HEIGHT (FT)
13     C      RML      =ROOM LENGTH (FT)
14     C      RMW      =ROOM WIDTH (FT)
15     C      AZM      =CLOCKWISE AZIMUTH OF ROOM FROM NORTH
16     C      RCN      =CEILING REFLECTANCE
17     C      RWL      =WALL REFLECTANCE
18     C      RFL      =FLOOR REFLECTANCE
19     C      RRF      =ROOF REFLECTANCE (IMMEDIATELY OUTSIDE CLFREESTORY)
20     C      RG       =GROUND REFLECTANCE
21     C      RX       =EXTERNAL OBSTRUCTION REFLECTANCE
22     C      NA       =NUMBER OF APERTURES IN ROOM
23     C      NL       =NUMBER OF BANKS OF LUMINAIRES CONNECTED TO A
24     C                LIGHTING CONTROL DEVICE
25     C      RMN      =ROOM NUMBER
26     C
27     C      SKY VARIABLES:
28     C
29     C      SUNALT    =SUN ALTITUDE ABOVE THE HORIZONTAL
30     C      SUNAZ     =SUN AZIMUTH CLOCKWISE FROM NORTH
31     C      SRD      =SOLAR RADIATION DIFFUSE HORZ.(BTU/SF-HR)
32     C      SRT      =SOLAR RADIATION TOTAL ON HORZ.(BTU/SF-HR)
33     C      CR       =CLOUD RATIO, DIFFUSE/TOTAL SOLAR RADIATION
34     C      ZLUM     =ZENITH SKY LUMINANCE
35     C
36     C      WINDOW VARIABLES:
37     C
38     C      W        =WIDTH OF WINDOW
39     C      H        =HEIGHT OF WINDOW
40     C      H1       =HEIGHT OF WINDOW SILL FROM FLOOR
41     C      W1       =WIDTH OF WINDOW'S LEFT EDGE FROM WALL'S LEFT EDGE
42     C      T        =VISIBLE TRANSMITTANCE
43     C      M        =CORRECTION FOR MULLIONS
44     C      HX       =HEIGHT OF EXTERNAL OBSTRUCTION
45     C      DX       =DISTANCE OF EXTERNAL OBSTRUCTION FROM ROOM
46     C      SN       =WALL SURFACE ASSOCIATED WITH APERTURE
47     C                1-NORTH SURFACE
48     C                2-EAST SURFACE
49     C                3-SOUTH SURFACE
50     C                4-WEST SURFACE
51     C      OP       =HORIZONTAL OVERHANG PROJECTION (FEET)
52     C      AW       =DISTANCE FROM CEILING TO TOP OF WINDOW (FEET)
53     C      FP       =FIN PROJECTION FROM FENESTRATION (FEET)
54     C
55     C      SKYLIGHT VARIABLES:
56     C
57     C      W        =WIDTH OF SKYLIGHT

```



```

58      C      L      =LENGTH OF SKYLIGHT
59      C      L1     =DISTANCE (IN LENGHT DIRECTION) OF SKYLIGHT FROM
60      C              ROOM REFERENCE
61      C      W1     =DISTANCE (IN WIDTH DIRECTION) OF SKYLIGHT FROM
62      C              ROOM REFERENCE
63      C      T      =EFFECTIVE VISIBLE TRANSMITTANCE OF SKYLIGHT W/ WELL
64      C              (ENTER NEGATIVE VALUE IF TRANSLUCENT)
65      C      M      =CORRECTION FOR MULLIONS
66      C      WX     =WELL EXTENTION(DEPTH OF SKYLIGHT WELL)
67      C      RX     =WELL REFLECTANCE
68      C      SN     =5 FOR CEILING SURFACE
69      C
70      C      CLERESTORY (AND ROOF MONITOR) VARIABLES:
71      C      WC     =WIDTH OF CLERESTORY OPENING
72      C      LC     =LENGTH OF CLERESTORY OPENING
73      C      HC(-)  =TOTAL HEIGHT OF SLOPED CLERESTORY (ABOVE CEILING PLANE)
74      C      HC(+)  =TOTAL HEIGHT OF SQUARE MONITOR CLERESTORY (ABOVE CEILING PLANE)
75      C      W      =WIDTH OF WINDOW IN CLERESTORY
76      C      H      =HEIGHT OF WINDOW IN CLERESTORY
77      C      H1     =HEIGHT OF CLERESTORY WINDOW SILL FROM CEILING
78      C      W1     =WIDTH OF CLERESTORY WINDOW'S LEFT EDGE FROM CLERESTORY
79      C              WALL
80      C      LC1    =DISTANCE(IN LENGTH DIRECTION) OF CLERESTORY
81      C              FROM ROOM REFERENCE
82      C      WC1    =DISTANCE(IN WIDTH DIRECTION) OF CLERESTORY
83      C              FROM ROOM REFERENCE
84      C      T      =VISIBLE TRANSMITTANCE OF GLAZING
85      C      M      =CORRECTION FOR MULLIONS
86      C      SN     =6 FOR CLERESTORY/MONITOR NORTH SURFACE
87      C              7 FOR CLERESTORY/MONITOR EAST SURFACE
88      C              8 FOR CLERESTORY/MONITOR SOUTH SURFACE
89      C              9 FOR CLERESTORY/MONITOR WEST SURFACE
90      C
91      C      DIMMER VARIABLES:
92      C
93      C      PW     =WIDTH DISTANCE OF SENSOR POINT FROM SOUTH WALL (FT)
94      C      PL     =LENGTH DISTANCE OF SENSOR POINT FROM WEST WALL (FT)
95      C      DILL   =DESIGN ILLUMINANCE (FC)
96      C      DIM    =DIMMER SYSTEM (ON/OFF=1,STEP-DOWN=2,CONT DIMMING W/MIN=3,
97      C              DIMMING W/OFF=4)
98      C      LOAD   =CONNECTED LIGHT LOAD ASSOCIATED WITH SENSOR (KW)
99      C      CHI    =CONSTANT (MIN) OFFSET DIM CONTROL COEFFICIENT(DEFAULT=0.30)
100     C      XI     =LINEAR DIM CONTROL COEFFICIENT(DEFAULT=0.30)
101     C
102     C      PARAMETER MMM=42
103     C      PARAMETER NNL=10
104     C      REAL LOAD,LLOAD,LLOADX,LLOADN,L,LC,L1,L2,M
105     C      COMMON /DD/ZLITE(MMM,12),DAYLT(NNL)
106     C      DIMENSION COEF(NA,NL),SURFAZ(*),WINAZ(NA,NL),THETA(NA,NL),
107     C      *WP(NA,NL),DP(NA,NL)
108     C      PI=3.14159
109     C      IF(ZLITE(2,4).LE.0.)GO TO 90 @CHECKS IF IT IS DAY OR NIGHT
110     C      RMH=ZLITE(1,1)
111     C      RML=ZLITE(1,2)
112     C      RMW=ZLITE(1,3)
113     C      AZM=ZLITE(1,4)
114     C      DO 30 I=1,NL
115     C      DAYLT(I)=0.

```

```

116      30 CONTINUE
117      GRDLIT=0.
118      LLOADX=0.
119      NN=NA+3
120      NST=ZLITE(1,11)+32
121      C
122      DO 70 K=NN,NST @FOR EACH OF NL POSSIBLE FIXTURE BANKS
123      C
124      IF(ZLITE(K,1).EQ.0.)GO TO 70
125      PW =ZLITE(K,1)
126      PL =ZLITE(K,2)
127      DILL=ZLITE(K,3)
128      DIM =ZLITE(K,4)
129      LOAD=ZLITE(K,5)
130      N =K-32
131      MST=MMM>NNL
132      C
133      DO 60 J=3,MST @FOR EACH OF NA POSSIBLE APERTURES
134      C
135      IF(ZLITE(J,9).LE.0.)GO TO 60
136      T =ZLITE(J,5)
137      M =ZLITE(J,6)
138      SN=ZLITE(J,9)
139      ISN=SN
140      IF(SN.GE.6)SURFAZ(ISN)=90.*(SN-6)+AZM
141      IF(SN.LT.6)SURFAZ(ISN)=90.*(SN-1)+AZM
142      IF(ITEST.GT.1)GO TO 50 @IF COEFFICIENTS ALREADY OBTAINED
143      C
144      C CALCULATE DAYLIGHT GEOMETRY COEFFICIENTS
145      C THESE COEFFICIENTS ARE CALCULATED INITIALLY AND STORED
146      C FOR HOURLY USE
147      C
148      IF((ZLITE(J,9).EQ.0.).OR.(ZLITE(J,5).EQ.0.))GO TO 60
149      W =ZLITE(J,1)
150      W1=ZLITE(J,4)
151      C
152      C DEFINE LOCAL COORDINATES (THESE ARE DISTANCES AS SEEN BY
153      C THE FENESTRATION,OR ANGLES AS VIEWED THROUGH THE FENESTRATION)
154      C
155      C WINAZ(J,N) =FENESTRATION AZIMUTH ANGLE @ CENTRIOD
156      C THETA(J,N) =FENESTRATION ALTITUDE ANGLE @ CENTROID
157      C SURFAZ(ISN)=WALL SURFACE AZIMUTH (DEGREES FROM NORTH)
158      C
159      C COORDINATES FOR ROOM SURFACE 1
160      C
161      IF(SN.EQ.1)THEN
162      WP(J,N)=RML-PL
163      DP(J,N)=RMW-PW
164      RW=RMW
165      RL=RML
166      IF(W1.GE.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)-ATAN((W1-WP(J,N)+.5*W)/
167      *DP(J,N))*57.3
168      IF(W1.LT.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)+ATAN((WP(J,N)-W1-.5*W)/
169      *DP(J,N))*57.3
170      C
171      C COORDINATES FOR ROOM SURFACE 2
172      C
173      ELSE IF (SN.EQ.2) THEN

```

```

174      WP(J,N)=PW
175      DP(J,N)=RML-PL
176      RW=RML
177      RL=RMW
178      IF(W1.GE.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)-ATAN((W1-WP(J,N)+.5*W)/
179 *DP(J,N))*57.3
180      IF(W1.LT.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)+ATAN((WP(J,N)-W1-.5*W)/
181 *DP(J,N))*57.3
182
183 C
184 C      COORDINATES FOR ROOM SURFACE 3
185 C
186      ELSE IF (SN.EQ.3) THEN
187          WP(J,N)=PL
188          DP(J,N)=PW
189          RW=RMW
190          RL=RML
191      IF(W1.GE.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)-ATAN((W1-WP(J,N)+.5*W)/
192 *DP(J,N))*57.3
193      IF(W1.LT.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)+ATAN((WP(J,N)-W1-.5*W)/
194 *DP(J,N))*57.3
195
196 C
197 C      COORDINATES FOR ROOM SURFACE 4
198 C
199      ELSE IF (SN.EQ.4) THEN
200          WP(J,N)=RMW-PW
201          DP(J,N)=PL
202          RW=RML
203          RL=RMW
204      IF(W1.GE.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)-ATAN((W1-WP(J,N)+.5*W)/
205 *DP(J,N))*57.3
206      IF(W1.LT.WP(J,N))WINAZ(J,N)=SURFAZ(ISN)+ATAN((WP(J,N)-W1-.5*W)/
207 *DP(J,N))*57.3
208
209 C
210 C      COORDINATES FOR CEILING SURFACE 5
211 C
212      ELSE IF (SN.EQ.5) THEN
213          L =ZLITE(J,2)
214          L1=ZLITE(J,3)
215          DP(J,N)=RMH-2.5
216          L2=L1-PL
217          W2=W1-PW
218          IF((L2.GT.0.).AND.(W2.LT.0.))AZM=AZM+90. @IN DEGREES
219          IF((L2.LT.0.).AND.(W2.LT.0.))AZM=AZM+180. @IN DEGREES
220          IF((L2.LT.0.).AND.(W2.GT.0.))AZM=AZM+270. @IN DEGREES
221          IF(AZM.LE.360.)AZM=0.
222          IF(L1.LT.PL)L2=PL-L-L1
223          IF(W1.LT.PW)W2=PW-W-W1
224          IF(W2+W/2.EQ.0.)THEN
225              WINAZ(J,N)=AZM
226          ELSE
227              WINAZ(J,N)=ATAN((L2+L/2)/(W2+W/2))*57.3+AZM @IN DEGREES
228          END IF
229          IF((L2+L/2.EQ.0.).AND.(W2+W/2.EQ.0.))THEN
230              THETA(J,N)=90.
231          ELSE
232              THETA(J,N)=ATAN(DP(J,N)/SQRT((L2+L/2)**2+(W2+W/2)**2))*57.3 @IN DEGREES
233          END IF

```

```

232 C COORDINATES FOR CLERESTORY SURFACE 6
233 C
234 ELSE IF (SN.EQ.6) THEN
235 H1=ZLITE(J,3)
236 LC=ZLITE(J,11)
237 LC1=ZLITE(J,8)
238 WC=ZLITE(J,10)
239 WC1=ZLITE(J,7)
240 DP(J,N)=RMH-2.5+H1
241 WP(J,N)=RML-PL
242 RW=RMW
243 RL=RML
244 IF((WC1+WC).LT.PW)WINAZ(J,N)=SURFAZ(ISN) @NOTE:DSF=0.
245 IF(LC1.GE.PL)WINAZ(J,N)=SURFAZ(ISN)+ATAN((LC1-PL+.5*LC)/
246 * (WC1+WC-PW))*57.3
247 IF(LC1.LT.PL)WINAZ(J,N)=SURFAZ(ISN)-ATAN((PL-LC1-.5*LC)/
248 * (WC1+WC-PW))*57.3
249 C
250 C COORDINATES FOR CLERESTORY SURFACE 7
251 C
252 ELSE IF (SN.EQ.7) THEN
253 H1=ZLITE(J,3)
254 LC=ZLITE(J,11)
255 LC1=ZLITE(J,8)
256 WC=ZLITE(J,10)
257 WC1=ZLITE(J,7)
258 DP(J,N)=RMH-2.5+H1
259 WP(J,N)=PW
260 RW=RML
261 RL=RMW
262 IF(((LC1+LC).GE.PL).AND.(WC1.GE.PW))WINAZ(J,N)=SURFAZ(ISN)-
263 * ATAN((WC1-PW+.5*W)/(LC1+LC-PL))*57.3
264 IF(((LC1+LC).GE.PL).AND.(WC1.LT.PW))WINAZ(J,N)=SURFAZ(ISN)+
265 * ATAN((PW-WC1-.5*W)/(LC1+LC-PL))*57.3
266 IF((LC1+LC).LT.PL)WINAZ(J,N)=SURFAZ(ISN) @NOTE:DSF=0.
267 C
268 C COORDINATES FOR CLERESTORY SURFACE 8
269 C
270 ELSE IF (SN.EQ.8) THEN
271 H1=ZLITE(J,3)
272 LC=ZLITE(J,11)
273 LC1=ZLITE(J,8)
274 WC=ZLITE(J,10)
275 WC1=ZLITE(J,7)
276 DP(J,N)=RMH-2.5+H1
277 WP(J,N)=PL
278 RW=RMW
279 RL=RML
280 IF(WC1.GT.PW)WINAZ(J,N)=SURFAZ(ISN) @NOTE:DSF=0.
281 IF(LC1.GE.PL)WINAZ(J,N)=SURFAZ(ISN)-ATAN((LC1-PL+.5*LC)/
282 * (WC1+WC-PW))*57.3
283 IF(LC1.LT.PL)WINAZ(J,N)=SURFAZ(ISN)+ATAN((PL-LC1-.5*LC)/
284 * (WC1+WC-PW))*57.3
285 C
286 C COORDINATES FOR CLERESTORY SURFACE 9
287 C
288 ELSE IF (SN.EQ.9) THEN
289 H1=ZLITE(J,3)

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```

290      LC=ZLITE(J,11)
291      LC1=ZLITE(J,8)
292      WC=ZLITE(J,10)
293      WC1=ZLITE(J,7)
294      DP(J,N)=RMH-2.5+H1
295      WP(J,N)=RMW-PW
296      RW=RML
297      RL=RMW
298      IF((LC1+LC).LT.PL)WINAZ(J,N)=SURFAZ(ISN) @NOTE:DSF=0.
299      IF((LC1+LC).GE.PL).AND.(WC1.GE.PW))WINAZ(J,N)=SURFAZ(ISN)+
300      * ATAN((WC1-PW+.5*W)/(LC1+LC-PL))*57.3
301      IF((LC1+LC).GE.PL).AND.(WC1.LT.PW))WINAZ(J,N)=SURFAZ(ISN)-
302      * ATAN((PW-WC1-.5*W)/(LC1+LC-PL))*57.3
303      END IF
304      50 CONTINUE
305      C
306      C CALCULATE ANGULAR CORRECTION OF GLAZING TRANSMITTANCE
307      C (CORRECTS FOR SUNLIGHT GRAZING ANGLE)
308      C
309      SUNALT=ZLITE(2,1) @IN DEGREES
310      SUNAZ =ZLITE(2,2) @IN DEGREES
311      IF(SUNAZ.GT.360.)SUNAZ=SUNAZ-360.
312      AZ=ABS(SUNAZ-WINAZ(J,N))
313      IF (AZ.GT.90.)THEN
314      ANG=0.
315      ELSE
316      ANG=ATAN(SQRT(TAN(SUNALT*PI/180.))**2+SIN(AZ*PI/180.))**2)
317      */COS(AZ*PI/180.))
318      END IF
319      TNX=1.018*T*COS(ANG)*(1.+SIN(ANG)**3)
320      C
321      C CALCULATE SKY LUMINANCE AS SEEN THROUGH THE FENESTRATION
322      C
323      CALL SKYLUM(SURFAZ(ISN),WINAZ(J,N),THETA(J,N),PL,PW,WP(J,N),
324      *DP(J,N),J,SKYLIT,SUNLIT,GRDLIT,SIDLIT)
325      IF(ITEST.GT.1)GO TO 55
326      C
327      C CALCULATE ROOM ILLUMINANCE AT SENSOR LOCATION
328      C
329      CALL RMLITE(WP(J,N),DP(J,N),PL,PW,RW,RL,J,SKYLIT,SUNLIT,
330      *GRDLIT,XLITE)
331      COEF(J,N)=XLITE
332      55 CONTINUE
333      IF((T.LT.0).AND.(SN.EQ.5))DAYLTE=COEF(J,N)*GRDLIT*ABS(T)*M
334      IF((T.LT.0).AND.(SN.NE.5))DAYLTE=COEF(J,N)*SIDLIT*ABS(T)*M
335      IF(T.GT.0)DAYLTE=SUNLIT*TNX*M+COEF(J,N)*T*M*SKYLIT
336      IF(T.EQ.0)DAYLTE=0.
337      DAYLT(N)=DAYLT(N)+DAYLTE
338      60 CONTINUE
339      C
340      C CALCULATE ADJUSTED LIGHTING LOAD
341      C
342      DAYLTE=DAYLT(N)
343      XI=0.70
344      CHI =0.30
345      IF(ZLITE(K,6).GT.0.)XI=ZLITE(K,6)
346      IF(ZLITE(K,7).GT.0.) CHI=ZLITE(K,7)
347      LLOADN=LLOAD(DAYLTE,DILL,DIM,LOAD,XI,CHI)
348      ZLITE(K,10)=DAYLTE
349      ZLITE(K,11)=LLOADN
350      ZLITE(K,12)=GRDLIT
351      70 CONTINUE
352      90 RETURN
353      END

```


BLOCK DIAGRAM - PREDICTS SKY CONDITIONS

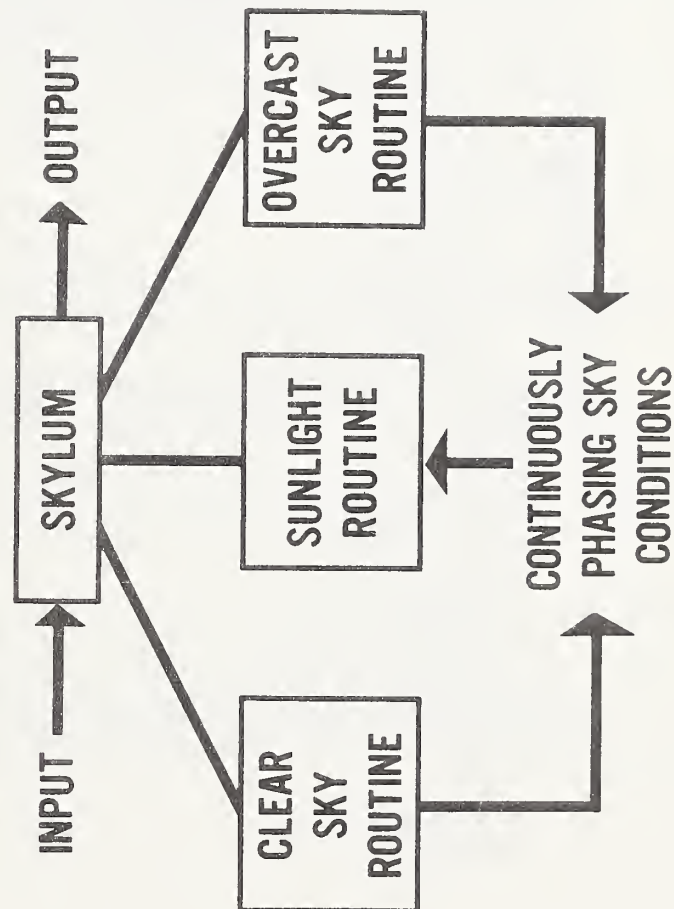


Figure E.2 Block diagram for predicting sky conditions

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Q$Q$Q$*GARY(1).SKYLUM(31)
1      SUBROUTINE SKYLUM(SURFAZ,WINAZ,THETA,PL,PW,WP,DP,J,SKYLIT,
2      *SUNLIT,GRDLIT,SIDLIT)
3      C
4      C      TO CALCULATE THE SKY LUMINANCE AS SEEN THRU A WINDOW/SKYLIGHT
5      C
6      C      SUNALT=SOLAR ALTITUDE ANGLE (DEGREES ABOVE HORIZON)
7      C      SUNAZ =SOLAR AZIMUTH ANGLE (DEGREES CLOCKWISE FROM NORTH)
8      C      BETA  =HAZINESS FACTOR:RURAL=0.05 URBAN=0.10 INDUSTRIAL=0.20
9      C      WINAZ =VEIWIN WINDOW AZIMUTH ANGLE @ CENTER AS SEEN BY
10     C      POINT ON WORK PLANE (DEGREES CLOCKWISE FROM NORTH)
11     C      THETA =VEIWIN WINDOW ALTITUDE ANGLE @ CENTER AS SEEN BY
12     C      POINT ON WORK PLANE (INPUT IN DEGREES ABOVE HORIZON)
13     C      CR    =CLOUD RATIO,DIFFUSE/TOTAL SOLAR RADIATION
14     C      (CLOUD COVER/100. COULD BE USED IN LIU OF CR,BUT W/ SOME
15     C      LOSS OF ACCRURACY)
16     C      SRT   =TOTAL SOLAR RADIATION,HORIZONTAL(BTU/HR/SF)
17     C      SRD   =DIFFUSE SOLAR RADIATION,HORIZONTAL(BTU/HR/SF)
18     C      SKYLUM=SKY LUMINANCE @ WINDOW CENTROID (FOOTLAMBERTS)
19     C      CLRSKY=CLEAR SKY LUMINANCE @ WINDOW OR SKYLIGHT CENTROID
20     C      OVRSKY=OVERCAST SKY LUMINANCE @ WINDOW OR SKYLIGHT CENTROID
21     C      SUNLIT=DIRECT SUN ILLUMINANCE ON THE HORIZONTAL
22     C      SUNBM =DIRECT BEAM ILLUMINANCE AT NORMAL INCIDENCE
23     C
24     COMMON/DD/ZLITE(42,12),DAYLT(10)
25     REAL L,L1,LC,LC1
26     RMH  =ZLITE(1,1)
27     AZM  =ZLITE(1,4)
28     SUNALT=ZLITE(2,1)
29     SUNAZ =ZLITE(2,2)
30     SRD   =ZLITE(2,3)
31     SRT   =ZLITE(2,4)
32     BETA  =ZLITE(2,5)
33     OMEGA =ZLITE(2,6)
34     JUL   =ZLITE(2,8)
35     SN    =ZLITE(J,9)
36     PI    =3.14159
37     IF(SUNAZ.GT.360.)SUNAZ=SUNAZ-360.
38     IF(SN.EQ.5)THEN @FOR HORIZONTAL SKYLIGHTS
39         X=0.
40         H =0.
41         H1=0.
42         W =ZLITE(J,1)
43         L =ZLITE(J,2)
44         L1=ZLITE(J,3)
45         W1=ZLITE(J,4)
46         HX=ZLITE(J,7)
47         DX=ZLITE(J,8)
48         OP=ZLITE(J,10)
49         THETA=THETA*PI/180.
50         HWP =0.
51     ELSE IF(SN.LT.5)THEN @FOR VERTICAL WINDOWS
52         X=0.
53         L =0.
54         L1=0.
55         W =ZLITE(J,1)
56         H =ZLITE(J,2)
57         H1=ZLITE(J,3)

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58      W1=ZLITE(J,4)
59      HX=ZLITE(J,7)
60      DX=ZLITE(J,8)
61      OP=ZLITE(J,10)
62      AW=ZLITE(J,11)
63      HWP=H+H1-2.5
64      HH=HX*(DP/(DP+DX))
65      THETA=ATAN((HWP-(HWP-HH)/2)/DP) @IN RADIANS
66  ELSE IF(SN.GT.5)THEN @FOR CLERESTORIES
67      W =ZLITE(J,1)
68      H =ZLITE(J,2)
69      H1=ZLITE(J,3)
70      W1=ZLITE(J,4)
71      WC1=ZLITE(J,7)
72      LC1=ZLITE(J,8)
73      WC=ZLITE(J,10)
74      LC=ZLITE(J,11)
75      HC=ZLITE(J,12)
76      OP=0.
77      AW=DP
78      IF(SN.EQ.6)X=WC+WC1-PW
79      IF(SN.EQ.7)X=LC+LC1-PL
80      IF(SN.EQ.8)X=PW-WC1
81      IF(SN.EQ.9)X=PL-LC1
82      HWP=RMH+H1+H/2-2.5
83      THETA=ATAN(HWP/X) @IN RADIANS
84  END IF
85  IF(SRT.EQ.0.)GO TO 20
86  IF(THETA.LT.0.)THETA=0.
87  C
88  C  CALCULATE INTERMEDIATE CLOUD-MODIFIED SKY LUMINANCE
89  C
90      CR =SRD/SRT
91      PHASE =(1.+COS(PI*CR))/2.
92      SKYLIT=CLRSKY(SUNALT,SUNAZ,WINAZ,THETA,BETA,OMEGA)*PHASE
93      *+OVRSKY(SRD,THETA)*(1.-PHASE)
94  C
95  C  CALCULATE SUNLIGHT PRESENT AT SENSOR POSITION
96  C
97      IF(SUNALT.LT.5)THEN
98      SUNBM=0. @CONTROLS PROBLEM DUE TO LOW SUN ANGLES
99      ELSE
100     SUNBM=SUNN(SUNALT,SUNAZ,AZM,H,H1,W,W1,L,L1,OP,AW,WP,
101     *PL,PW,DP,DX,SN,JUL,X)*PHASE
102     SUNLIT=SUNBM*SIN(SUNALT*PI/180.)
103     END IF
104  C
105  C  CALCULATE OUTDOOR HORIZONTAL & VERTICAL ILLUMINATION
106  C
107     AZ=ABS(SURFAZ-SUNAZ)
108     GRDLIT=(93.+18.*CR)*SRT*.2931 @ILLUMINANCE ON GROUND(FC)
109     IF(AZ.GE.90.)SIDLIT=.5*111.*SRD*.2931 @(FC)
110     IF(AZ.LT.90.)SIDLIT=(.5*111.*SRD*.2931)
111     *+(SUNBM*COTAN(SUNALT*PI/180.)) @ILLUMINANCE ON VERTICAL(FC)
112 20 RETURN
113  END

```

```

Q$Q$Q$*GARY(1).SUNN(9)
1      FUNCTION SUNN(SUNALT,SUNAZ,AZM,H,H1,W,W1,L,L1,OP,AW,WP,
2      *PL,PW,DP,DX,SN,JUL,X)
3
4      C      SUBROUTINE TO CALCULATE THE DIRECT SUN CONDITIONS
5      C
6      C      SUNAZ =SUN'S AZIMUTH (DEGREES CLOCKWISE FROM NORTH)
7      C      SUNALT=SUN'S ALTITUDE (DEGREES ABOVE HORIZON)
8      C      JUL   =JULIAN DATE(JAN 1=1,DEC 31=365)
9      C      AZM   =CLOCKWISE AZIMUTH COORDINATES OF WALL OFF N-S AXIS
10     C      EX    =EXTRATERRESTRIAL ILLUMINANCE NORMAL TO SUN (FOOT-CANDLES)
11     C      SUNN  =DIRECT SUNLIGHT ILLUMINANCE NORMAL TO SUN (FOOT-CANDLES)
12     C
13     REAL L,L1,LS1,LS2
14     PI    =3.14159
15     SUNN  =0.0
16     IF(SN.GT.5)DP=X
17     EX=11840.*(1+.033*COS(.99*JUL*PI/180.)) @EXTRATERRESTRIAL ILLUMINANCE (FC)
18
19     C      ALGORITHM TO DETERMINE THE SOLAR DISC ILLUMINANCE
20     C      PROJECTED ON THE WORKPLANE FROM A VERTICAL WINDOW OR CLERESTORY
21     C
22     ANGL1=ABS(ATAN((W+W1-WP)/DP)*180./PI)
23     ANGL2=ABS(ATAN((W1-WP)/DP)*180./PI)
24     IF((SN.EQ.1).OR.(SN.EQ.6))THEN
25         GO TO 60
26     ELSE IF((SN.EQ.2).OR.(SN.EQ.7))THEN
27         IF(SUNAZ.GT.(180.+AZM))GO TO 60
28         DS1=(H+H1+AW)/TAN((SUNALT*PI/180.)/
29     *   COS(ABS(SUNAZ-90.-AZM)*PI/180.))-OP
30     ANGL3=90.+AZM-ANGL1
31     ANGL4=90.+AZM+ANGL2
32     ELSE IF((SN.EQ.3).OR.(SN.EQ.8))THEN
33         IF((SUNAZ.LT.(90.+AZM)).OR.(SUNAZ.GT.(270.+AZM)))GO TO 60
34         DS1=(H+H1+AW)/TAN((SUNALT*PI/180.)/
35     *   COS(ABS(SUNAZ-180.-AZM)*PI/180.))-OP
36     ANGL3=180.+AZM-ANGL1
37     ANGL4=180.+AZM+ANGL2
38     ELSE IF((SN.EQ.4).OR.(SN.EQ.9))THEN
39         IF(SUNAZ.LT.(180.+AZM))GO TO 60
40         DS1=(H+H1+AW)/TAN((SUNALT*PI/180.)/
41     *   COS(ABS(SUNAZ-270.-AZM)*PI/180.))-OP
42     ANGL3=270.+AZM-ANGL1
43     ANGL4=270.+AZM+ANGL2
44     ELSE
45         GO TO 50          @FOR(SN.EQ.5)
46     END IF
47     IF((SUNAZ.LT.ANGL3).OR.(SUNAZ.GT.ANGL4))GO TO 60
48     DS2=0.          @INITIALIZE
49     IF(SN.LT.5)DS2=(DS1+OP)*H1/(H1+H+AW)
50     IF(SN.GT.5)DS2=DS1*(H1+AW)/(H+H1+AW)
51     IF((DP.GT.DS1).OR.(DP.LT.DS2))GO TO 60
52     SUNN=EX*EXP(-.21/SIN(SUNALT*PI/180.))
53     GO TO 60
54
55     C      ALGORITHM TO DETERMINE THE SOLAR DISC ILLUMINANCE
56     C      PROJECTED ON THE WORKPLANE FROM A HORIZONTAL SKYLIGHT
57     C

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```

58      50 SANGL1=SUNALT+(90.-SUNALT)*ABS(COS(SUNAZ*PI/180.))
59      IF((SANGL1.EQ.90.).OR.(SANGL1.EQ.270.))THEN
60      LS1=L1
61      ELSE
62      IF(SUNAZ.LE.180.)LS1=L1-(DP+DX)/TAN(SANGL1*PI/180.)
63      IF(SUNAZ.GT.180.)LS1=L1+(DP+DX)/TAN(SANGL1*PI/180.)
64      END IF
65      LS2=LS1+L
66      IF((PL.LT.LS1).OR.(PL.GT.LS2))GO TO 60
67      SUNN=EX*EXP(-.21/SIN(SUNALT*PI/180.))
68      SANGL2=SUNALT+(90.-SUNALT)*ABS(SIN(SUNAZ*PI/180.))
69      IF(SANGL2.EQ.90.)WS1=W1
70      IF(SANGL2.NE.90.)WS1=W1+(DP+DX)/TAN(SANGL2*PI/180.)
71      WS2=WS1+W
72      IF((PW.LT.WS1).OR.(PW.GT.WS2))SUNN=0.
73      60 CONTINUE
74      RETURN
75      END

```



```

Q$Q$Q$*GARY(1).CLRSKY(25)
1      FUNCTION CLRSKY(SUNALT,SUNAZ,WINAZ,THETA,BETA,OMEGA)
2      C
3      C      SUBROUTINE TO CALCULATE THE CLEAR SKY LUMINANCE AT THE
4      C      CENTROID OF THE WINDOW/SKYLIGHT
5      C
6      C      (INPUT VALUES FOR CLRSKY ARE CONVERTED TO RADIAN BELOW)
7      C      SUNALT=SOLAR ALTITUDE IN DEGREES ABOVE HORIZON
8      C      ZLUM =ZENITH SKY LUMINANCE (FOOTLAMBERTS)
9      C      AZ =AZIMUTH ANGLE BETWEEN SUN AND VIEW POINT OF GLAZING
10     C      THETA =ALTITUDE ANGLE OF GLAZING VIEW POINT
11     C      GAMA =SOLID ANGLE BETWEEN SUN AND GLAZING VIEW POINT
12     C      OMEGA =ATMOSPHERIC MOISTURE COEFFICIENT
13     C      BETA =ATMOSPHERIC TURBIDITY COEFFICIENT
14     C
15     DIMENSION A0(6,3),A1(6,3)
16     DATA(A0(J,1),J=1,6)/0.9361,0.9093,0.8727,0.8547,0.8460,0.8410/
17     DATA(A0(J,2),J=1,6)/1.0329,1.0206,1.0074,1.0019,0.9990,0.9980/
18     DATA(A0(J,3),J=1,6)/1.1399,1.1499,1.1698,1.1833,1.1899,1.1968/
19     DATA(A1(J,1),J=1,6)/0.0020,0.0018,0.0014,0.0012,0.0011,0.0011/
20     DATA(A1(J,2),J=1,6)/0.0024,0.0022,0.0019,0.0017,0.0016,0.0016/
21     DATA(A1(J,3),J=1,6)/0.0030,0.0028,0.0025,0.0023,0.0022,0.0021/
22     PI=3.14159
23     IF(BETA.LE.0.05)IBETA=1
24     IF((BETA.GT.0.05).AND.(BETA.LE.0.10))IBETA=2
25     IF(BETA.GT.0.10)IBETA=3
26     IF(OMEGA.LE.0.5)IOMEGA=1
27     IF((OMEGA.GT.0.5).AND.(OMEGA.LE.1.0))IOMEGA=2
28     IF((OMEGA.GT.1.0).AND.(OMEGA.LE.2.0))IOMEGA=3
29     IF((OMEGA.GT.2.0).AND.(OMEGA.LE.3.0))IOMEGA=4
30     IF((OMEGA.GT.3.0).AND.(OMEGA.LE.4.0))IOMEGA=5
31     IF(OMEGA.GT.4.0)IOMEGA=6
32     SALT =SUNALT*PI/180. @IN RADIAN
33     ZLUM =(A0(IOMEGA,IBETA)+A1(IOMEGA,IBETA)*SUNALT**2)*291.9
34     AZ =ABS((SUNAZ-WINAZ)*PI/180.) @IN RADIAN
35     GAMA =ACOS(SIN(THETA)*SIN(SALT)+COS(THETA)*COS(SALT)*COS(AZ))
36     CLRSKY=ZLUM*(0.910+10.*EXP(-3*GAMA)+0.45*COS(GAMA)*COS(GAMA))*
37     *(1.-EXP(-0.32/SIN(THETA)))/(0.27385*(0.91+10.*EXP(-3*(1.57-SALT))
38     *+0.45*SIN(SALT)*SIN(SALT)))
39     RETURN
40     END

```

Q\$Q\$Q\$*GARY(1).OVRSKY(17)

```
1      FUNCTION OVRSKY(SRD,THETA)
2      C
3      C      SUBROUTINE TO CALCULATE THE  OVERCAST SKY LUMINANCE AT THE
4      C      CENTROID OF THE WINDOW/SKYLIGHT
5      C
6      C      ZLUM  =ZENITH SKY LUMINANCE (FOOTLAMBERTS)
7      C      OVRSKY=OVERCAST SKY LUMINANCE OF APERTURE MIDPOINT
8      C      THETA =ALTITUDE ANGLE STUDY POINT MAKES WITH APERTURE MIDPOINT
9      C
10     PI=3.14159
11     C
12     C      CALCULATE ZENITH LUMINANCE
13     C
14     ZLUM=(111.*SRD*.2931)*9/7
15     C
16     C      CALCULATE OVERCAST SKY LUMINANCE AT WINDOW VIEW ANGLE
17     OVRSKY=ZLUM*{(1.+2.*SIN(THETA))/3.)
18     RETURN
19     END
```

BLOCK DIAGRAM - PREDICTS ROOM CONDITIONS

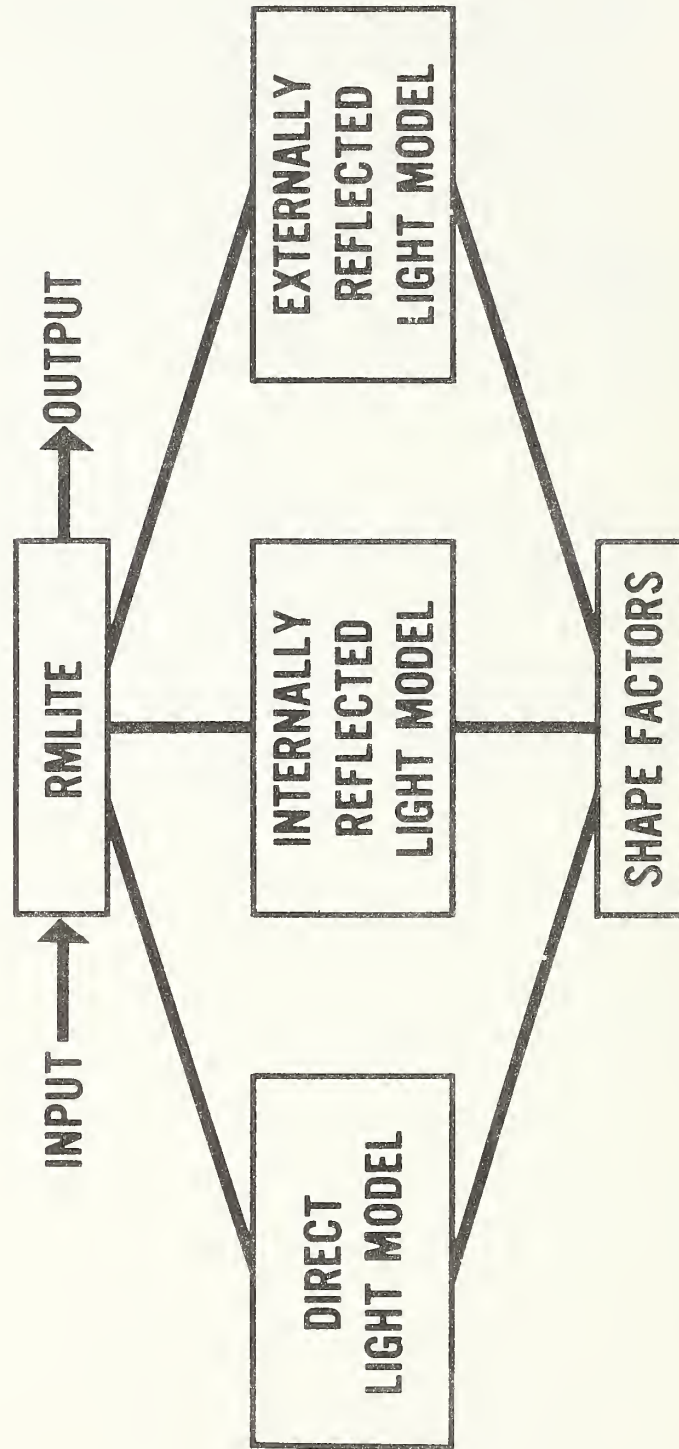


Figure E.3 Block diagram for predicting room daylight conditions

Q\$Q\$Q\$*GARY(1).RMLITE(36)

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1      SUBROUTINE RMLITE(WP,DP,PL,PW,RW,RL,J,
2      *SKYLIT,SUNLIT,GRDLIT,XLITE)
3
4      C      THIS ROUTINE CALCULATES THE COMBINED ILLUMINANCE COEFFICIENTS
5      C      USED TO OBTAIN TOTAL WORKPLANE ILLUMINANCE.
6
7      C      DP      =DEPTH OF THE REFERENCE POINT FROM THE APERTURE SURFACE(FEET).
8      C      T      =TRANSMISSION COEFFICIENT OF WINDOW OR SKYLIGHT
9      C      (NEGATIVE IF TRANSLUCENT)
10     C      WA      =WINDOW OR SKYLIGHT AREA, SQ. FT.
11     C      A      =ROOM INTERNAL SURFACE AREA
12     C      RX      =REFLECTANCE OF EXTERNAL OBSTRUCTION OR SKYLIGHT WELL
13     C      RFW     =AVERAGE REFLECTANCE FACTOR OF THE LOWER HALF OF THE ROOM
14     C      RCW     =AVERAGE REFLECTANCE FACTOR OF THE UPPER HALF OF THE ROOM
15     C      RAVE    =AVERAGE REFLECTANCE OF THE ENTIRE ROOM
16     C      W      =WINDOW OR SKYLIGHT WIDTH, FT.
17     C      L      =SKYLIGHT LENGTH, FT.
18     C      H      =WINDOW HEIGHT, FT.
19     C      HL      =PROJECTED HEIGHT OF OBSTRUCTION ON WINDOW
20     C      HX      =HEIGHT OF OBSTRUCTION FROM WORK PLANE
21     C      DX      =DISTANCE OF OBSTRUCTION FROM WINDOW
22     C      WX      =SKYLIGHT WELL DEPTH
23     C      RMH     =ROOM HEIGHT
24     C      RML     =ROOM LENGTH
25     C      RMW     =ROOM WIDTH
26     C      RW      =APPARENT ROOM WIDTH (USED IN INTER-REFLECTION MODEL)
27     C      RL      =APPARENT ROOM LENGTH (USED IN INTER-REFLECTION MODEL)
28     C      WP      =DISTANCE FROM CORNER OF ROOM TO PERP. REFERENCE LINE
29     C      H1      =SILL HEIGHT ABOVE FLOOR
30     C      W1      =DISTANCE FROM LEFT MOST CORNER OF WINDOW OR SKYLIGHT
31     C      TO LEFT MOST CORNER OF WALL SURFACE(IN "WIDTH" DIRECTION)
32     C      L1      =DISTANCE LEFT MOST CORNER OF SKYLIGHT TO LEFT MOST
33     C      CORNER OF WALL SURFACE(IN LENGTH DIRECTION)
34     C      M      =CORRECTION FOR GLAZING MULLIONS
35     C      T      =COMBINED EFFECTIVE TRANSMITTANCE OF THE GLAZING
36     C      TNX     =ANGULAR DEPENDENT TRANSMITTANCE
37     C      RG      =GROUND REFLECTANCE
38     C      JUL     =JULIAN DATE
39     C      DAYLTE=INTERIOR DAYLIGHT ILLUMINATION
40     C      XDL     =DIRECT LIGHT FROM THE SKY
41     C      XERL    =EXTERNALLY REFLECTED LIGHT (FROM OBSTRUCTING BUILDINGS)
42     C      RRL     =ROOF REFLECTED LIGHT ENTERING CLERISTORY
43     C      XIRL    =INTERNALLY REFLECTED LIGHT (FROM ROOM SURFACES)
44     C      SKYLIT=SKY LUMINANCE @APERTURE CENTROID(AVERAGE APERTURE LUMINANCE)
45     C      SUNLIT=HORIZONTAL ILLUMINANCE FROM THE DIRECT SUN
46     C      GRDLIT=TOTAL HORIZONTAL GROUND ILLUMINATION(SKY&SUN)
47     C      SIDLIT=VERTICAL SURFACE ILLUMINANCE(SKY ONLY)
48     C      GRL     =GROUND REFLECTED LIGHT COEFFICIENT
49     C      SNL     =SUNLIGHT COEFFICIENT
50     C
51     COMMON/DD/ZLITE(42,12),DAYLT(10)
52     REAL M,L,L1,LC,LC1
53     PI=3.14159265
54     RMH   =ZLITE(1,1)
55     RML   =ZLITE(1,2)
56     RMW   =ZLITE(1,3)
57     RCN   =ZLITE(1,5)

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58      RWL      =ZLITE(1,6)
59      RFL      =ZLITE(1,7)
60      RG       =ZLITE(1,8)
61      RX       =ZLITE(1,9)
62      SUNALT   =ZLITE(2,1)
63      JUL      =ZLITE(2,8)
64      T        =ZLITE(J,5)
65      M        =ZLITE(J,6)
66      SN       =ZLITE(J,9)
67      OP       =ZLITE(J,10)
68      AW       =ZLITE(J,11)
69      FP       =ZLITE(J,12)
70
71      C
72      C      FOR THE FOUR ROOM SURFACES
73      C
74      IF(SN.LT.5)THEN
75          W=ZLITE(J,1)
76          H=ZLITE(J,2)
77          H1=ZLITE(J,3)
78          W1=ZLITE(J,4)
79          HX=ZLITE(J,7)
80          DX=ZLITE(J,8)
81          WA=W*H
82          HH=HX*DP/(DP+DX)
83          HL=HH-H1+2.5
84          HH1=H+H1-2.5
85          IF(HL.GT.H)HH=H
86
87      C
88      C      FOR CEILING SURFACE
89      C
90      ELSE IF(SN.EQ.5)THEN
91          W=ZLITE(J,1)
92          L=ZLITE(J,2)
93          L1=ZLITE(J,3)
94          W1=ZLITE(J,4)
95          HX=ZLITE(J,7)
96          DX=ZLITE(J,8)
97          H =L
98          HL=0.
99
100      C
101      C      FOR CLERESTORY SURFACES
102      C
103      ELSE IF(SN.GT.5)THEN
104          W =ZLITE(J,1)
105          H =ZLITE(J,2)
106          H1=ZLITE(J,3)
107          W1=ZLITE(J,4)
108          WC1=ZLITE(J,7)
109          LC1=ZLITE(J,8)
110          WC=ZLITE(J,10)
111          LC=ZLITE(J,11)
112          HC=ZLITE(J,12)
113          HH=0.
114          HH1=0.
115          HL=0.
116      END IF
117      XDL=0.
118
119      C

```



```

116 C    PREPARE VARIABLES FOR INTERREFLECTION SUBROUTINE
117 C
118 A=2.*((RML*RMH)+(RML*RMW)+(RMH*RMW))
119 ACN= RMW*RML
120 AWL=(RL*RMH)+2*(RW*RMH)
121 RAVE=(AWL*RWL+ACN*RFL+ACN*RCN+(W*H)*.15+(RL*RMH-W*H)*RWL)
122 */(AWL+ACN+ACN+RL*RMH)
123 IF(SN.GT.4)GO TO 10
124 C
125 C    CALCULATE CORRECTION FOR EXTERIOR FINS & OVERHANGS
126 C
127 IF(HL.GE.H)GO TO 20
128 IF((OP.GT.0.).AND.(ATAN(AW/OP).LT.ATAN(HH1/DP)))HH1=DP*(HH1+AW)/
129 *(OP+DP) @CORRECTION FOR OVERHANG
130 IF(FP.GT.0.)W=W-(FP*W/2/(DP+FP)) @CORRECTION FOR SIDE FINS
131 @ASSUMES WINDOW CENTRIOD REPRESENTATIVE
132 10 CONTINUE
133 C
134 C    CALCULATE THE DIRECT LIGHT CONFIGURATION COEFFICIENT BETWEEN THE
135 C    FENESTRATION AND A POINT IN THE ROOM.
136 C
137 C
138 CALL DL(XDL,CRL,RRL,HH1,HH,W,WP,DP,PL,PW,GRDLIT,J)
139 C
140 C    CALCULATE THE EXTERNALLY REFLECTED LIGHT
141 C
142 IF(SN.GE.5)XERL=0.
143 20 IF(SN.LT.5)XERL=ERL(W,H,W1,H1,HH,WP,DP)*RX @EXTERNAL REF LIGHT
144 C
145 C    CALCULATE THE SUNLIGHT INTENSITY ENTERING ROOM
146 C    & THE GROUND LIGHT AS COEFFICIENTS
147 C
148 IF(SUNALT.LT.5.)THEN
149 SNL=0. @CONTROLS PROBLEMS DUE TO LOW SUN ANGLES
150 ELSE
151 SNL=SUNLIT/(ABS(T)*M*SKYLIT)
152 IF((SN.GE.6).AND.(XDL.EQ.CRL))SNL=SUNLIT/GRDLIT
153 END IF
154 GRL=GRDLIT/(ABS(T)*M*SKYLIT)
155 C
156 C    CALCULATE INTERNALLY REFLECTED LIGHT
157 C
158 CALL IRL(J,HH,RL,RW,RAVE,A,GRL,SNL,CRL,XIRL) @INTERNAL REF LIGHT
159 C
160 C    CALCULATE DAYLIGHT ILLUMINANCE
161 C    NOTE: NEGATIVE TRANSMITTANCE MEANS TRANSLUCENT GLAZING
162 C
163 IF((SN.GE.6).AND.(XDL.EQ.CRL))T=1.0
164 XRRL=RRL/(T*M*SKYLIT)
165 IF((T.LT.0.).AND.(SN.EQ.5))XLITE=XDL+XIRL
166 IF((T.LT.0.).AND.(SN.NE.5))XLITE=XDL+XIRL-XERL
167 IF((SN.GE.6).AND.(XDL.EQ.CRL))XLITE=XIRL
168 IF((T.GT.0.).AND.(T.NE.1))XLITE=XDL+XERL+XIRL+XRRL
169 IF(T.EQ.0.)DAYLTE=0.
170 RETURN
171 END

```

```

Q$Q$Q$*GARY(1).DL(19)
1      SUBROUTINE DL(XDL,CRL,RRL,HH1,HH,W,WP,DP,PL,PW,GRDLIT,J)
2      C
3      C      DL =DIRECT LIGHT FROM SKY ON A POINT IN THE ROOM.
4      C      THIS ROUTINE CALCULATES POINT ILLUMINANCE COEFFICIENTS
5      C      OF THE DIRECT SKY COMPONENT FOR WINDOWS,HORIZONTAL SKYLIGHTS,
6      C      AND CLERESTORIES.
7      C
8      COMMON /DD/ZLITE(42,12),DAYLT(10)
9      REAL L,L1,L2,L3,LC,LC1,LC2
10     PI =3.14159265
11     PI2=PI/2
12     H =ZLITE(J,2)
13     H1 =ZLITE(J,3)
14     W1 =ZLITE(J,4)
15     SN =ZLITE(J,9)
16     RCN=ZLITE(1,5)
17     RG =ZLITE(1,8)
18     XDL=0. @INITIALIZE
19     CRL=0. @INITIALIZE
20     ZERO=0.
21     IF(SN.GE.5)GO TO 30
22     C
23     C      WINDOW ROUTINE
24     C
25     H2 =2.5-H1
26     H2A=ABS(H2)
27     W4 =WP-W1-W
28     W5 =WP-W1
29     IF(HH.GE.HH1)GO TO 40
30     IF(HH.EQ.0.)THEN
31         IF(H2.LE.0.)XDL=BCF(W,H,DP,W5,H2A,PI2)
32         IF(H2.GT.0.)XDL=BCF(W,HH1,DP,W5,ZERO,PI2)
33     ELSE
34         HH4=H-HH
35         HH6=HH-H2
36         XDL=BCF(W,HH4,DP,W4,HH6,PI2)
37     END IF
38     GO TO 40
39     30 CONTINUE
40     C
41     C      MODEL DIRECT LIGHT FROM TOPLIGHTING(OVERHEAD FENESTRATION)
42     C
43     WC1=ZLITE(J,7)
44     LC1=ZLITE(J,8)
45     WC =ZLITE(J,10)
46     LC =ZLITE(J,11)
47     HC =ZLITE(J,12)
48     IF(HC.GT.0.)PSI=90. @ROOF MONITOR CHECK
49     HC=ABS(HC)
50     X =PL-LC1
51     Y =PW-WC1
52     ZZ =DP
53     IF(SN.EQ.5)THEN
54     C
55     C      SKYLIGHT ROUTINE
56     C
57     C      ASSUMES USE OF EFFECTIVE TRANS FOR LIGHT WELL EFFECTS

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58      C
59      A = 0.
60      L = ZLITE(J,2)
61      L1 = ZLITE(J,3)
62      WX = ZLITE(J,8)
63      ZZ = DP + WX
64      W2 = W1 - PW
65      L2 = L1 - PL
66      IF (W2.GE.0.) THEN
67          W3 = W2 + W
68      ELSE
69          W3 = ABS(W2)
70          W2 = ABS(W2) - W
71      END IF
72      IF (L2.GE.0.) THEN
73          L3 = L2 + L
74          IF (L2.EQ.0) L3 = L
75      ELSE
76          L3 = ABS(L2)
77          L2 = ABS(L2) - L
78      END IF
79      IF (W3.LE.W) THEN
80          W2 = W - W3
81          W3 = W
82          IF (L3.LE.L) THEN
83              L2 = L - L3
84              L3 = L
85              XDL = BCFS(W3,L3,ZZ,A) + BCFS(W3,L2,ZZ,A)
86          *      + BCFS(W2,L3,ZZ,A) + BCFS(W2,L2,ZZ,A)
87      ELSE
88          L2 = L2 + ((WX*L2)/DP)
89          XDL = BCFS(W3,L3,ZZ,A) - BCFS(W3,L2,ZZ,A)
90      *      + BCFS(W2,L3,ZZ,A) - BCFS(W2,L2,ZZ,A)
91      END IF
92      ELSE
93          W2 = W2 + ((WX*W2)/DP)
94          IF (L3.LE.L) THEN
95              L2 = L - L3
96              L3 = L
97              XDL = BCFS(W3,L3,ZZ,L2) - BCFS(W2,L3,ZZ,L2)
98          ELSE
99              L2 = L2 + ((WX*L2)/DP)
100          XDL = BCFS(W3,L3,ZZ,A) - BCFS(W2,L3,ZZ,A)
101      *      - BCFS(W3,L2,ZZ,A) + BCFS(W2,L2,ZZ,A)
102      END IF
103      END IF
104      C
105      C      CLERESTORY ROUTINE (INCLUDING ROOF MONITORS)
106      C
107      ELSE IF ((SN.EQ.6).OR.(SN.EQ.8)) THEN
108          XX = Y
109          IF (SN.EQ.8) XX = WC - Y
110          YY = X - W1
111          IF (SN.EQ.8) YY = W + W1 - X
112          CC = SQRT(WC**2 + HC**2)
113          IF (PSI.EQ.90.) CC = WC
114          CC2 = CC/2
115          LC2 = LC/2

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116      WC2=WC/2
117      C
118      C      CALCULATE ROOF REFLECTED LIGHT: RRL
119      C
120      IF(PSI.EQ.90.)THEN
121          PHI=0.
122          A =HC
123          ZZ =DP+HC
124      ELSE
125          A =WC2*SIN(PHI)
126      END IF
127      B1=CC2*SIN(PHI)
128      B2=H-B1
129      C =SQRT(WC2**2+A**2)
130      RRL=BCF(LC,B2,C,LC2,A,PHI)*RG*GRDLIT
131      **BCF(LC,CC,XX,YY,ZZ,PHI)*RCN
132      IF(PSI.EQ.90)GO TO 10
133      C
134      C      CALCULATE CEILING REFLECTED LIGHT: CRL
135      C
136      XX =WC-Y
137      HHC=HC-H-H1
138      CRL=BCF(LC,CC,XX,YY,ZZ,PHI)*BCF(W,H,CC2,LC2,HHC,PSI)*RCN
139      10 CONTINUE
140      C
141      C      CALCULATE DIRECT LIGHT: XDL
142      C
143      XX =WC-Y
144      IF(SN.EQ.8)XX =Y
145      XDL=BCF(W,H,XX,YY,DP,PI2)+CRL
146      IF((SN.EQ.6).AND.(Y.GT.WC))XDL=CRL
147      IF((SN.EQ.8).AND.(Y.LT.0.))XDL=CRL
148      C
149      ELSE IF((SN.EQ.7).OR.(SN.EQ.9))THEN
150      XX =X
151      IF(SN.EQ.9)XX =LC-X
152      YY =Y
153      CC =SQRT(LC**2+HC**2)
154      IF(PSI.EQ.90)CC=LC
155      CC2=CC/2
156      LC2=LC/2
157      WC2=WC/2
158      C
159      C      CALCULATE ROOF REFLECTED LIGHT: RRL
160      C
161      PHI=ATAN(HC/LC)
162      PSI=PI/2-PHI
163      IF(PSI.EQ.90.)THEN
164          PHI=0.
165          A =HC
166          ZZ =DP+HC
167      ELSE
168          A=LC2*SIN(PHI)
169      END IF
170      B1=CC2*SIN(PHI)
171      B2=H-B1
172      C =SQRT(LC2**2+A**2)
173      RRL=BCF(WC,B2,C,WC2,A,PHI)*RG*GRDLIT

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174      **BCF(WC,CC,XX,YY,ZZ,PHI)*RCN
175      IF(PSI.EQ.90.)GO TO 200
176      C
177      C      CALCULATE CEILING REFLECTED LIGHT: CRL
178      C
179      HHC=HC-H-H1
180      CRL=BCF(WC,CC,XX,YY,DP,PHI)*BCF(W,H,CC2,WC2,HHC,PSI)*RCN
181      200 CONTINUE
182      C
183      C      CALCULATE DIRECT LIGHT: XDL
184      XDL=BCF(W,H,XX,YY,Z,PI2)+CRL
185      XX =LC-X
186      IF(SN.EQ.9)XX =X
187      IF((SN.EQ.7).AND.(X.GT.LC))XDL=CRL
188      IF((SN.EQ.9).AND.(X.LT.0.))XDL=CRL
189      END IF
190      400 RETURN
191      END

```


Q\$Q\$Q\$*GARY(1).IRL(50)

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1      SUBROUTINE IRL(J,HH,RL,RW,RAVE,A,GRL,SNL,CRL,XIRL)
2      C
3      C      COMPUTES THE INTER-REFLECTED LIGHT (FROM THE ROOM SURFACES)
4      C
5      C      RMH  =ROOM HEIGHT
6      C      RW   =APPARENT ROOM WIDTH (AS SEEN BY THE FENESTRATION)
7      C      RL   =APPARENT ROOM LENGTH (AS SEEN BY THE FENESTRATION)
8      C      RWL  =REFLECTANCE OF WALL
9      C      RCN  =REFLECTANCE OF CEILING
10     C      RFL  =REFLECTANCE OF FLOOR
11     C      XIRL =INTERNALLY REFLECTED LIGHT COEFFICIENT
12     C      GRL  =GROUND REFLECTED LIGHT COEFFICIENT
13     C      SNL  =SUNLIGHT COEFFICIENT
14     C
15     REAL LC,LC1
16     COMMON /DD/ZLITE(42,12),DAYLT(10)
17     RMH  =ZLITE(1,1)
18     RCN  =ZLITE(1,5)
19     RWL  =ZLITE(1,6)
20     RFL  =ZLITE(1,7)
21     RG   =ZLITE(1,8)
22     RX   =ZLITE(1,9)
23     SUNALT=ZLITE(2,1)
24     SUNAZ =ZLITE(2,2)
25     W     =ZLITE(J,1)
26     H     =ZLITE(J,2)
27     H1    =ZLITE(J,3)
28     W1    =ZLITE(J,4)
29     SN    =ZLITE(J,9)
30     PI    =3.14159
31     PI2   =PI/2
32     KOUNT=1
33     ZLITE(42,12)=ZLITE(42,12)+KOUNT
34     C
35     C      FOR INTER-REFLECTIONS FROM TOPLIGHTING(SKYLIGHTS & CLERESTORIES)
36     C
37     C      NOTE:LIGHT WELL & CLERESTORY CAVITY REFLECTED LIGHT
38     C      IS COMPUTED IN DL SUBROUTINE
39     C
40     IF(SN.EQ.5)SURFAZ=ZLITE(1,4)
41     IF(SN.GT.5)SURFAZ=90.*(SN-6)+ZLITE(1,4)
42     C
43     C      INTERNAL REFLECTIONS FROM SKYLIGHT
44     C
45     IF(SN.EQ.5)THEN
46     FLUX1=0.
47     FLUX2=0.
48     FLUX3=0.
49     FLUX4=0.
50     FLUX5=W*H*GRL      @FLUX FROM SKYLIGHT
51     SUNFLX=SNL*W*H*RFL @FLUX FROM THE SUN
52     C
53     C      INTERNAL REFLECTIONS FROM CLERESTORY
54     C
55     ELSE IF(SN.GT.5)THEN
56     WC1=ZLITE(J,7)
57     LC1=ZLITE(J,8)

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58      WC =ZLITE(J,10)
59      LC =ZLITE(J,11)
60      IF(SN.EQ.6)THEN
61          XX=WC1+WC
62          YY=LC1+LC-W1-W
63      ELSE IF(SN.EQ.7)THEN
64          XX=LC1+LC
65          YY=WC1+W1
66      ELSE IF(SN.EQ.8)THEN
67          XX=RW-WC1
68          YY=LC1+W1
69      ELSE IF(SN.EQ.9)THEN
70          XX=RW-LC1
71          YY=WC1-W1-W
72      END IF
73      ZZ=RMH/2+H1
74      FLUX1=0.
75      FLUX2=0.
76      BCF3 =BCF(W,H,XX,YY,ZZ,PI2)      @FLUX FROM BACK(OPPOSITE) WALL
77      FLUX3=BCF3*RL*RMH*RWL
78      FLUX4=0.
79      FLUX5=0.
80      SUNFLX=SNL*W*H*RWL @FLUX FROM THE SUN
81      CNFLX=CRL*LC*WC*RCN
82      C
83      ELSE IF(SN.LT.5)THEN
84          FP =ZLITE(J,10)
85          AW =ZLITE(J,11)
86      C
87      C      FOR INTER-REFLECTIONS FROM SIDELIGHTING
88      C
89      RL2  =RL/2
90      RH2  =RMH/2
91      RW2  =RW/2
92      HH1  =H+H1-2.5
93      HH2  =RMH/2-HH-2.5
94      HH3  =RMH/2-H1
95      HH4  =H-(HH3-HH2)
96      HH5  =RMH/2-HH2
97      H2   =2.5-H1
98      H3   =H1+H
99      H4   =RMH-H1-H2
100     H5   =RMH-H1-H
101     H6   =RMH-H1
102     W2   =W1+W
103     W3   =RL2-W1
104     W6   =RL-W2
105     W7   =RL-W1
106     ZERO =0.
107     SURAZ=90.*(SN-1)+ZLITE(1,4)
108     C
109     C      CALCULATE INTERNALLY REFLECTED FLUX FROM THE SUNLIGHT
110     C
111     AZS=ABS(SUNAZ-SURAZ)
112     IF(AZS.GE.90.)THEN
113         SUNFLX=0.
114     ELSE
115         PHI=(SUNALT*PI/180.)/COS(AZS*PI/180.)

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116          IF(AW.LT.(FP*TAN(PHI)))DS1=RMH/TAN(PHI)-FP
117          IF(AW.GE.(FP*TAN(PHI)))DS1=(RMH-AW)/TAN(PHI)-FP
118          DS2=H1/TAN(PHI)
119          DS3=FP*(TAN(AZS*PI/180.))
120          IF(DS3.GT.0.)W=W-DS3
121          SUNFLX=SNL*W*(DS1-DS2)*RFL      @FLUX FROM THE SUN
122      END IF
123      C
124      C      CALCULATE FLUX FROM CEILING
125      C
126          BCFCN=BCF(W,H,RW2,W3,H5,PI2)
127          CNFLX=BCFCN*RW*RL*RCN*RG*GRL
128      C
129      C      CALCULATE FLUX FOR EACH WALL SURFACE
130      C
131          SUMFLX=ZLITE(33,9)
132          IF(ZLITE(42,12).GT.KOUNT)GO TO 10
133      C
134      C      WINDOW WALL SURFACE 1
135      C
136          FLUX1=0      @SINCE WINDOW WALL HAS LITTLE REFLECTED LIGHT
137      C
138      C      LEFT SIDE SURFACE 2
139      C
140          IF(RX.EQ.0.)BCF2=BCF(H,W,RW2,HH3,W1,PI2)
141          IF(RX.GT.0.)BCF2=BCF(HH4,W,RW2,HH2,W1,PI2)
142          *      +BCF(HH1,W,RW2,HH3,W1,PI2)*RX
143          FLUX2=BCF2*RMH*RW*RWL
144      C
145      C      BACK WALL SURFACE 3
146      C
147          IF(RX.EQ.0.)BCF3=BCF(W,H,HH3,W3,RW,ZERO)
148          IF(RX.GT.0.)BCF3=BCF(W,HH4,HH2,W3,RW,ZERO)
149          *      +BCF(W,HH1,HH3,W3,RW,ZERO)*RX
150          FLUX3=BCF3*RMH*RL*RWL
151      C
152      C      RIGHT SURFACE 4
153      C
154          IF(RX.EQ.0.)BCF4=BCF(H,W,RW2,HH3,W6,PI2)
155          IF(RX.GT.0.)BCF4=BCF(HH4,W,RW2,HH2,W6,PI2)
156          *      +BCF(HH1,W,RW2,HH3,W6,PI2)*RX
157          FLUX4=BCF4*RMH*RW*RWL
158      C
159      C      FLOOR SURFACE 5
160      C
161          IF(RX.EQ.0.)BCF5=BCF(W,H,RW2,W3,H1,PI2)
162          IF(RX.GT.0.)BCF5=BCF(W,HH4,RW2,W3,HH5,PI2)
163          *      +BCF(W,HH1,RW2,W3,H1,PI2)*RX
164          FLUX5=BCF5*RW*RL*RFL
165      C
166      C
167      END IF
168      C
169      C      COMPUTES MULTIPLE INTER-REFLECTIONS (ASSUMING ULBRICHT SPHERE)
170      C
171          SUMFLX=(FLUX1+FLUX2+FLUX3+FLUX4+FLUX5)
172          */A/(1-RAVE)
173      10 IF(SN.LT.5)ZLITE(33,9)=SUMFLX

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174      XIRL=SUMFLX+((CNFLX+SUNFLX)/A/(1-RAVE))  
175      RETURN  
176      END
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Q$Q$Q$*GARY(1).ERL(31)
1      FUNCTION ERL(W,H,W1,H1,HH,WP,DP)
2      C
3      C      ERL      = EXTERNALLY REFLECTED LIGHT FROM SURROUNDING BLDGS
4      C
5      HWP=H1+H
6      W4 =WP-W1
7      W5 =W4-W
8      H2 =H1-2.5
9      H2A=ABS(H2)
10     W5A=ABS(W5)
11     W4A=ABS(W4)
12     IF(W5.GT.0) GO TO 1
13     IF(W5.LT.0) GO TO 2
14     ERL=BCFW(W,HH,DP)-BCFW(W,H2A,DP)
15     GO TO 3
16     1 ERL=BCFW(W4,HH,DP)-BCFW(W1,HH,DP)-BCFW(W4,H2A,DP)+BCFW(W1,H2A,DP)
17     GO TO 3
18     2 IF(W4.LT.0.)ERL=BCFW(W5A,HH,DP)-BCFW(W5A,H2A,DP)-BCFW(W4A,HH,DP)
19     *-BCFW(W4A,H2A,DP)
20     ERL=BCFW(W4,HH,DP)+BCFW(W5A,HH,DP)-BCFW(W4,H2A,DP)
21     *-BCFW(W5A,H2A,DP)
22     3 RETURN
23     END
END PRT

@PRT,S GARY.BCF,.BCFS,.BCFW,.LLOAD

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Q\$Q\$Q\$*GARY(1).BCF(6)

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1      FUNCTION BCF(M,F,X,Y,Z,PHI)
2      C
3      C      BCF=BASIC CONFIGURATION FACTOR (PIERPOINT/HOPKINS EQUATION)
4      C      M F=SURFACE WIDTH & HEIGHT RESPECTIVELY(IN FEET)
5      C      XYZ=X,Y,&Z COORDINATES TO SURFACE'S LOWER LEFT CORNER(IN FEET)
6      C      PHI=SURFACE DECLINATION ANGLE (IN RADIAN)
7      C
8      REAL M
9      PI =3.14159265
10     G  =Z*SIN(PHI)-X*COS(PHI)
11     H  =Z*COS(PHI)+X*SIN(PHI)
12     A  =SQRT(X**2+Z**2)
13     A1 =A**2+Y**2-Y*M
14     B  =SQRT(X**2+Z**2+F**2+2*F*G)
15     B1 =B**2+Y**2-Y*M
16     C  =SQRT(Y**2+H**2)
17     D  =SQRT((Y-M)**2+H**2)
18     E1 =0.0
19     E2 =0.0
20     C      DIVIDE CHECK
21     IF(A1.EQ.0.) A1 =0.0001
22     IF(B1.EQ.0.) B1 =0.0001
23     IF(A1.LE.0.) E1 =PI
24     IF(B1.LE.0.) E2 =PI
25     C
26     BCF=(X/A*(ATAN(M*A/(A1))+E1)
27     *+(F*COS(PHI)-X)/B*(ATAN(M*B/(B1))+E2)
28     *+Y*COS(PHI)/C*ATAN(F*C/(C**2+G**2+F*G))
29     *-(Y-M)*COS(PHI)/D*ATAN(F*D/(D**2+G**2+F*G)))/2/PI
30     RETURN
31     END

```

BLOCK DIAGRAM - PREDICTS LIGHTING ENERGY

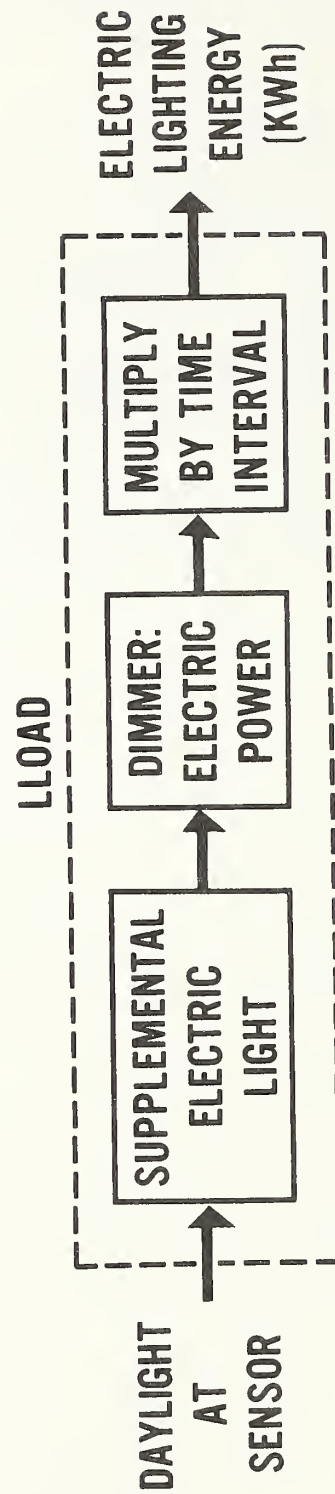


Figure 4. Block diagram for predicting electric lighting load

Q\$Q\$Q\$*GARY(1).BCFS(8)

```

1      FUNCTION BCFS(W,L,DP,A)
2      C
3      C      BCFS =BASIC CONFIGURATION FACTOR BETWEEN A HORIZONTAL SKYLIGHT AND
4      C      A HORIZONTAL WORKPLANE
5      C
6      C      W      =WIDTH OF SKYLIGHT
7      C      L      =LENGTH OF SKYLIGHT
8      C      A      =SHIFTED DISTANCE OF POINT ALONG REFERENCE EDGE
9      C      (NOTE: LENGTHS ARE HORIZONTAL DISTANCES IN THE DIRECTION OF
10     C      THE ROOM'S LENGTH(RML), THE WIDTHS ARE IN THE DIRECTION OF THE
11     C      ROOM'S WIDTH(RMW) )
12     C      DP      =DISTANCE FROM WORK PLANE TO BOTTOM OF SKYLIGHT
13     C
14     REAL L
15     PI=3.14159265
16     B =SQRT(DP*DP+L*L)
17     C =SQRT(DP*DP+A*A)
18     D =SQRT(DP*DP+(A-L)**2)
19     E =SQRT(DP*DP+W*W)
20     C      IF(A.GT.0.)BCFS=(A/C*ATAN(W/C)+W/E*ATAN(L*E/
21     C      *SQRT(A*A+DP*DP+W*W-A*L))+(L-A)/D*ATAN(W/D))/2./PI
22     BCFS=(L/B*ATAN(W/B)+W/E*ATAN(L/E))/2./PI
23     RETURN
24     END

```

```

Q$Q$Q$*GARY(1).BCFW(6)
  1      FUNCTION BCFW(W,H,D)
  2      C
  3      C      BCFW=BASIC CONFIGURATION FACTOR FOR A WINDOW
  4      C      (HIGBIE'S EQUATION FOR HORIZ. ILLUMINATION FROM VERTICAL WINDOW)
  5      C
  6      PI=3.14159265
  7      A=SQRT(D*D+H*H)
  8      BCFW=(ATAN(W/D)-D/A*ATAN(W/A))/2./PI
  9      RETURN
10      END

```

Q\$Q\$Q\$*GARY(1).LLOAD(8)

```
1      FUNCTION LLOAD(DAYLTE,DILL,DIM,LOAD,XI,CHI)
2      C
3      C      LLOAD =LIGHTING LOAD(HOURLY KW)
4      C
5      C      DAYLTE=DAYLIGHT ILLUMINANCE AT SENSOR
6      C      DILL  =DESIGN ILLUMINANCE(FOOTCANDLES) REQUIRED AT SENSOR LOCATION
7      C      DIM   =DIMMING STRATEGY,EITHER 1(ON/OFF),2(STEP DOWN),3(CONTINOUS),
8      C              OR 4(CONTINUOUS W/ OFF)
9      C      LOAD  =POWER LOAD(BEFORE DIMMING) ASSOCIATED WITH SENSOR LOCATION
10     C      XI    =LINEAR DIMMING COEFFICIENT
11     C      CHI   =CONSTANT DIMMING COEFFICIENT
12     C
13     REAL LOAD,LLOAD
14     PSL=(DILL-DAYLTE)/DILL  @DETERMINES PERCENT SUPPLEMENTAL LIGHT NEEDED
15     IF(PSL.GT.0.00) GO TO 1
16     IF(DIM.EQ.3)LLOAD=CHI*LOAD
17     LLOAD=0.0
18     GO TO 4
19     C
20     C      ON/OFF SWITCHING
21     C
22     1 IF(DIM.GT.1.0) GO TO 2
23     LLOAD=LOAD
24     GO TO 4
25     C
26     C      TWO LEVEL STEP-DOWN SWITCHING
27     C
28     2 IF(DIM.GT.2.0) GO TO 3
29     IF(PSL.GT.0.5) LLOAD=LOAD
30     IF(PSL.LE.0.5)LLOAD=LOAD*0.5
31     GO TO 4
32     C
33     C      CONTINUOUS DIMMING
34     C      (FLUORESCENT DIMMING IS DEFAULT)
35     C
36     3 LLOAD=(CHI+XI*PSL)*LOAD
37     4 RETURN
38     END
```

END PRT

@SEND IBM001

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here) A computer model is outlined for estimating the annual energy performance of a day-lighted building. The daylighting model is a system of FORTRAN subroutines designed for inclusion into larger building energy simulation programs such as DOE-2, BLAST, and NBSLD. Once incorporated into the main energy program, these subroutines will allow the existing program to account for the energy tradeoffs associated with natural illumination. The daylighting model, DALITE, comprises three separate routines to do three separate functions. The first routine generates hourly sky luminances and sky illuminances as well as direct sun illuminance, taking solar radiation and sun position data as input. The second predicts interior daylight illumination at various points within a room due to any number of windows, skylights or clerestories. The last routine adjusts the electric lighting load (via photoelectric controls) in response to the available day-light. Unlike other daylighting estimation techniques, this model is a dynamic model designed to study how conditions change with time. It has a further advantage in that it can be easily installed into most existing models written in FORTRAN 77.			
12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons) building computer simulation; building energy performance; clerestory performance; daylighting; skylight performance, window performance.			
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